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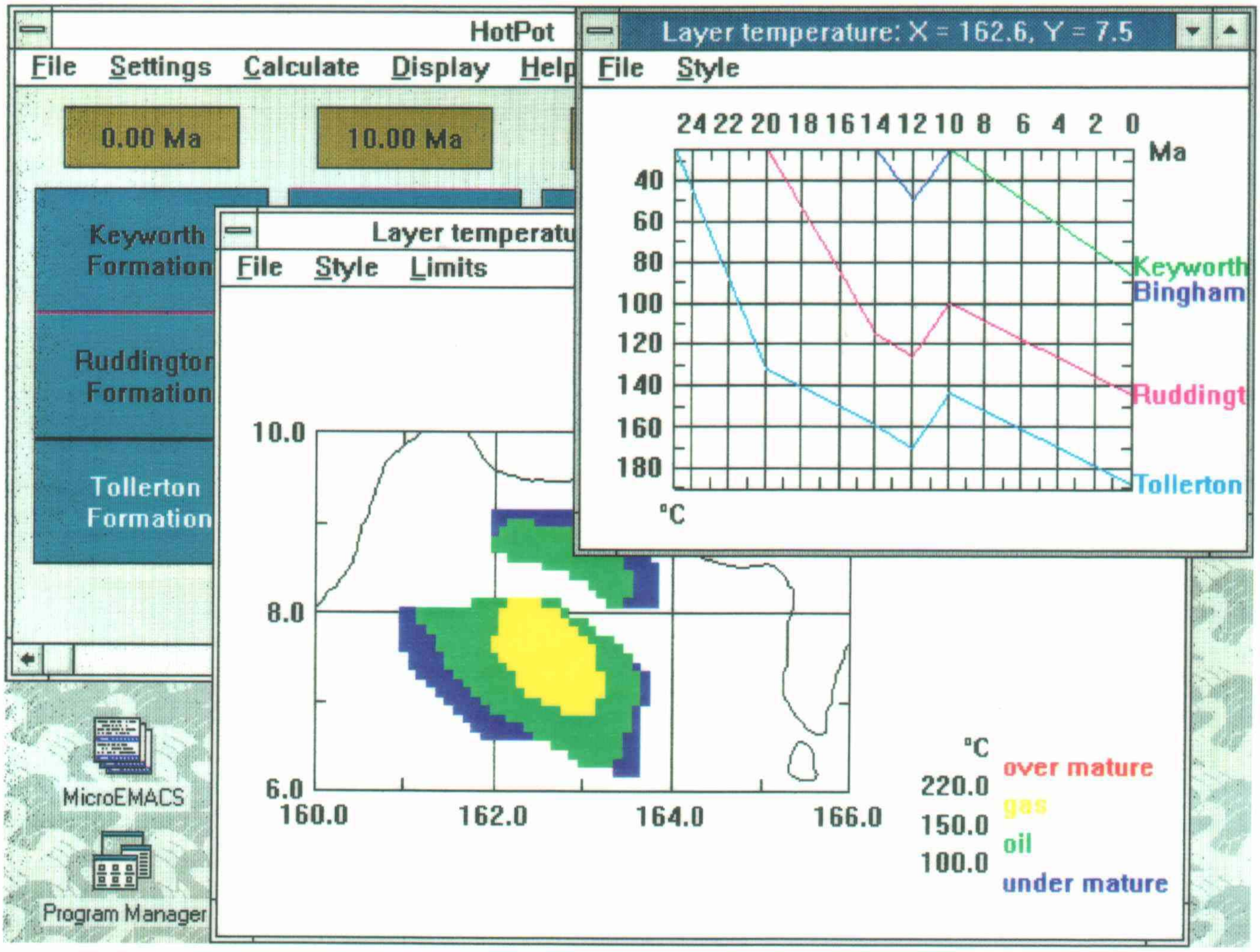
Basin Thermal Modelling using HotPot



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Basin Thermal Modelling using HOTPOT version 3.0

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Tectonics and Database Group

Subject index

Basin analysis; computer modelling; geothermal studies; hydrocarbon maturity; hydrocarbon prospectivity

Bibliographic reference

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SECTION 1

Introduction

1.1 Background

In 1989, at the request of the Technical Secretariat of the Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas (CCOP) and in collaboration with CCOP Member Countries, the British Geological Survey (BGS) began an investigation of the thermal history of petroliferous basins within the CCOP Region. The principal objective of the work was to develop, for use by the Member Countries, a system based on an IBM-compatible personal computer (PC) for the prediction of subsurface present-day and palaeotemperatures in sedimentary basins. To illustrate the feasibility and usefulness of the study a pilot study using data from the Gulf of Thailand and Malay basins was undertaken. The work was later extended to include other basins.

A preliminary version of the thermal modelling software, DECOMP3D (Rowley 1990), was distributed to the CCOP Technical Secretariat and to Member Countries in July 1990. This program formed the basis of the pilot study, which established the feasibility of the project and demonstrated the value of the results that could be achieved.

The BGS sediment decompaction and geothermal modelling program was renamed HOTPOT and redeveloped as a Microsoft Windows application in 1991-2. The first usage of the new software was in a study of the North Sumatra Basin. Modelling studies of the Subei – South Yellow Sea Basin of China were completed in early 1992.

In response to requests from the CCOP Technical Secretariat, and from Member Countries, a Workshop was arranged in order to demonstrate in detail the application of the then current version of HOTPOT, and to illustrate how its results might be interpreted and employed in hydrocarbon exploration. The Workshop was held at the Petronas Training Centre at Bangi, Malaysia, from 25 to 28 February 1992 and was attended by representatives from: CCOP Technical Secretariat, China, Indonesia, Malaysia, Thailand and Vietnam. The first public release of the HOTPOT program (Version 2.5) and user manual (Chadwick *et al.* 1992) was made at the Workshop.

Development of the HOTPOT program has continued throughout 1992-3, with the emphasis being on generalising the input-data specifications, to allow non-CCOP-specific data sets to be used, and improving the user interface. Feedback from users in the CCOP Technical Secretariat and CCOP Member Countries, together with experience gained from BGS modelling studies of the Northumberland – Solway Basin (UK) and the Bengal Basin (Bangladesh), has provided important information which enabled significant improvements to be made to some of the algorithms used in the program. The resulting program, HOTPOT Version 3.0, forms the second public release of the software.

1.2 Economic significance of thermal modelling

1.2.1 General statement

A review of the importance of temperature in geological processes in general is beyond the scope of this report. However, it is thought useful, at this preliminary stage, briefly to consider the

significance of temperature change with depth in sedimentary basins, and the necessity of predicting such changes.

Sedimentary basins are hosts to the world's oil, gas and coal reserves, and also contain a wide variety of minerals of economic interest and significant amounts of exploitable geothermal energy. Sedimentary rocks are also currently used or are being considered for short- or long-term disposal or storage of a variety of materials, including toxic and radioactive wastes, CO_2, natural gas and compressed air. Whether the requirement is for extraction, or for storage or disposal, accurate prediction of present-day subsurface temperatures is necessary.

The origin, distribution and development of certain economic materials such as oil, gas, coal and many mineral deposits is in part dependent on temperature. Hydrocarbons are generated by the action of heat on organic matter trapped and buried within sedimentary rocks. The progressive development from peat, through bituminous coal and semi-anthracite to anthracite is in large part a function of temperature. Many mineral deposits were formed from hot brines in the range 50-250°C. The assessment of present-day temperatures can at best only in part allow judgement on when and where such deposits might occur. A more complete evaluation, therefore, requires the prediction of palaeotemperatures which need to be considered in the light of the basin's tectonic and sedimentary history.

The main purpose of HOTPOT is the thermal modelling of sedimentary basins as an aid to hydrocarbon exploration. However, it should be emphasised that the program does have much wider applications in subsurface geological exploration and that there is a close genetic relationship between the generation of oil and gas, coal rank and the origin of strata-bound mineral deposits, many of which contain small amounts of hydrocarbons.

1.2.2 Generation of hydrocarbons

Temperature and time are the key parameters which determine hydrocarbon generation from organic-rich sediments. Waples (1980), following Lopatin (1971), introduced a Time-Temperature-Index (TTI) which attempted to predict the combined effects of time and temperature (vitrinite reflectance values) on organic matter in the subsurface. More recently, the theoretical basis of the TTI has been questioned and use made instead of chemical kinetic models (Wood 1988; Burnham & Sweeney 1989; Sweeney & Burnham 1990). However, in geologically young Cenozoic basins, temperature is probably a more important factor than time. Thus, MacKenzie & Quigley (1988) and Quigley & MacKenzie (1988) have suggested that most oil has formed between 100 and 150°C and most gas between 150 and 220°C.

Most of the petroliferous basins of the CCOP Region are of Cenozoic age. Therefore, accurate estimation of present-day and palaeo- subsurface temperatures, in particular the location of the 100°, 150° and 220° isotherms, is assumed to be sufficient to predict adequately the time and place of hydrocarbon generation from known source rocks. Such knowledge of the thermal history, allied with information relating to source potential, including kerogen-type, and to structural history, is a necessary pre-requisite in predicting the hydrocarbon prospectivity of any region.

1.3 Acknowledgements

It is a pleasure to record the co-operation and the support of past and present members of the CCOP Technical Secretariat, principally Dr G R Balce, Prof. Wang Daxiong, Mr Sermsakadi Kulvanich, Mr B Elishiwitz, Prof. He Qixiang, Prof. Weng Shijie, Dr N Hanaoka, Dr O Matsubayashi, Mr I Miljeteig, Mr S Maehle and Ms Petcharat Sarawisutra. The constructive advice of Prof. R Sinding-Larsen, Special Advisor from Norway to CCOP, is also acknowledged.

The project could not have proceeded without the generous support of Member Countries and their representatives at the Working Group on Resources Assessment (WGRA). The Department of

Mineral Resources (Thailand), through Mr Nares Sattayarak, and the Exploration Department of Petronas (Malaysia), through Mr Ho Wan Kin, provided data and valuable support to allow the pilot study to take place. Further data were supplied in support of later modelling by Lemigas (Indonesia), through Dr Ir Mujito, and the Institute of Marine Geology, Qingdao (China), through Mr Li Shaoquan. Mr Shuilin Zhao of the Institute of Geology, Yangzhou, China helped in testing and improving the program.

Thanks are due to colleagues at BGS for their help and advice during the project, notably to Dr G A Kirby, who reviewed the tutorial section of this report, and Ms B Birch, who helped with report production.

Special thanks go to Mr Ahmad Said and Petronas for their kind hospitality and logistical support of the 1992 Workshop.

The software development and the Workshop formed part of the ODA/BGS Research and Development Programme (Project numbers 91/23 and 92/13), funded by the United Kingdom Overseas Development Administration (ODA).

SECTION 2

Basin modelling with HOTPOT

This chapter will describe in general terms the principal features of the HOTPOT basin modelling software. HOTPOT is a self-contained 3-D sediment decompaction and thermal history modelling program. The Microsoft Windows 3 Graphical User Interface is used to provide a flexible system for controlling the program.

2.1 Data requirements

HOTPOT requires that the basin to be modelled (Fig. 2.1) is described as a series of stratigraphical units or layers (eroded layers can be incorporated into the basin model), which lie within a specified thermal regime defined by heatflow and surface temperature.

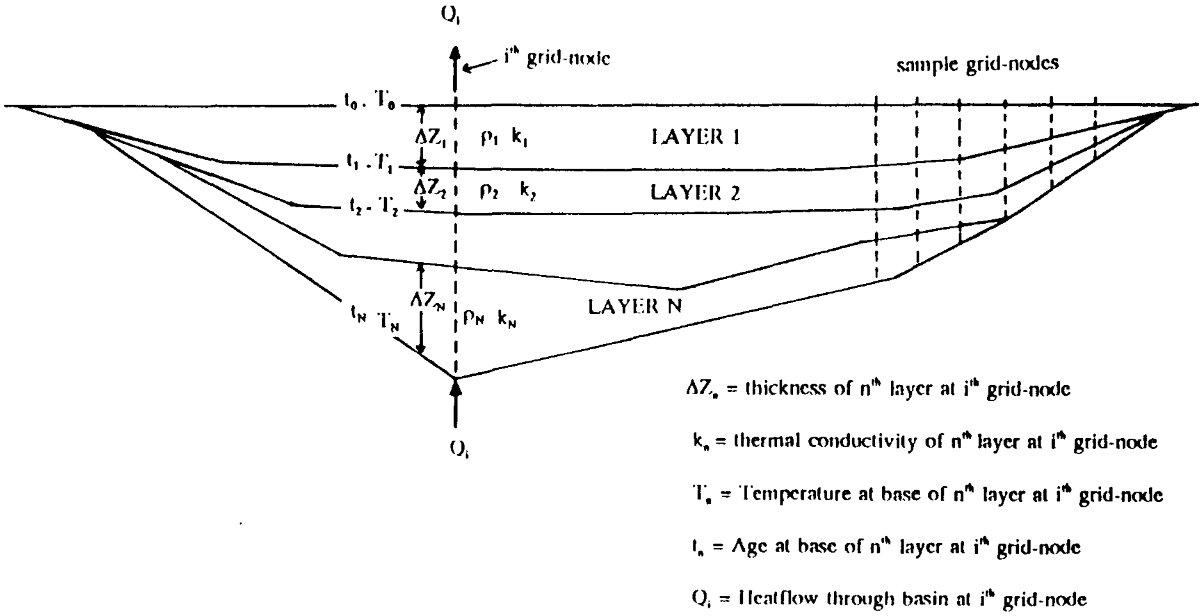


Figure 2.1: Schematic cross-section through a model sedimentary basin, illustrating the layer and thermal parameters

Data which relate directly to the stratigraphical layers and the thermal regime of the basin being modelled are referred to as *primary data.* Data which may relate to a wider area than the basin being modelled are referred to as *auxiliary data.*

2.1.1 Primary data

The primary data are sub-divided into *layer-related* and *age-related* groups.

Layer-related primary data

These data define the structure and properties of each individual layer in the basin being modelled.

The data required for each layer are:

a) *Either* a digitised isopach contour map showing the thickness distribution of the layer *or* a digitised depth contour map showing the depths to the base of the layer (see Notes, below). These digitised contour data are stored in data files; the various formats recognised by HOTPOT are described in Appendix II.

b) The average lithological composition of the layer expressed as relative proportions of the standard lithologies (conventionally: sandstone, limestone, silty mudstone and overpressured shale; but others may be used if the necessary auxiliary data are available). This information is entered via a Windows dialogue.

c) Chronological calibration of the base of the layer. This information is entered via a Windows dialogue.

d) If the layer has been eroded and is to be restored, chronological calibration of the onset of erosion. This information is entered via a Windows dialogue.

e) The water depth at the end of deposition of the layer. This information is entered via a Windows dialogue.

f) An average thermal conductivity value for the layer, where depth *vs.* thermal conductivity auxiliary data are not available. This information is entered via a Windows dialogue.

Notes:

1) All **normal** layers must be defined by *either* depth *or* isopach (thickness) data, the two types must not be mixed.

2) Any **eroded** layers in a model must be defined by isopach (thickness) data.

3) Where depth data are used, a topographic or bathymetric surface (either planar or gridded from digitised contour data) must be defined, in order to compute the thickness of the top layer.

Age-related primary data

The data pertinent to the ages of the layer boundaries are:

a) Heatflow information, expressed as either single basin-wide values, or digitised heatflow contour maps, or a combination of both. Digitised contour data are stored in data files; the various formats recognised by HOTPOT are described in Appendix II. Single values are entered via Windows dialogues.

b) Surface or seabed temperatures, expressed as single basin-wide values. Single values are entered via Windows dialogues.

2.1.2 Auxiliary data

In addition to the basin-specific data, HOTPOT requires auxiliary information to enable the backstripping–decompaction and thermal conductivity computations to be carried out.

a) Digitised density *vs.* depth curves for the standard lithologies (conventionally: sandstone, limestone, silty mudstone and overpressured shale) being used.

b) Digitised thermal conductivity *vs.* depth data for the same standard lithologies.

These digitised curves are stored in data files; the format is described in Appendix II. Ideally, auxiliary data should be prepared by the user, utilising information from the basin under study. However, if sufficient information is not available, the data files provided for use in the HOTPOT tutorial may be used. These are based upon typical basin sequences and are described in Appendix I.

2.2 Data processing

In HOTPOT, the primary and auxiliary data are loaded into a *model database* internal to the program. The decompaction and thermal calculation functions then operate on the database, generating new entries within it. Data may be extracted from the database for graphical display or for export to other programs. The Windows interface provides the user with a flexible method of controlling these processes.

Contour maps (depth, isopach and heatflow data) are a useful representation of spatially-varying data for geologists, but they are not readily manipulated by computer. For computational efficiency, spatially-varying data are better represented in terms of values at the intersections (*nodes*) of regularly spaced grids. For the spatial variation of different data types in an area to be compared, the grids used must have the same geographic limits and node-spacing, this is done by using a common *area-of-interest* specification.

The resultant overlaying gridded layers thus define the 3-D stratigraphical architecture and heatflow of the basin. Each basin grid-node has geographical (x, y) co-ordinates and several thickness and heatflow values corresponding to the layers through which it passes (Fig. 2.1). Thus, each basin grid-node holds the 1-D stratigraphy and burial history of that particular location.

Digitised contour maps input to HOTPOT are gridded using a distance-weighted moving-average algorithm, described in Appendix III. Nodes which lie outside of the basin, i.e. where data are not defined, have a NULL value.

2.2.1 Decompaction by backstripping

Layer-by-layer decompaction

As a stratigraphical sequence is laid down, the sedimentary layers are progressively compacted by the weight of overlying strata. Consequently, present-day preserved thicknesses are in general lower than original depositional thicknesses; the greater the depth of burial, the greater the discrepancy. In order to compute the true subsidence history of the basin it is necessary to correct for this effect. This is done by progressively decompacting the sediments by a procedure known as *backstripping*.

In HOTPOT, backstripping is carried out on a node-by-node basis, giving 1-D sediment decompaction at each grid-node.

The backstripping method in HOTPOT utilises the fact that as sediments are compacted, their porosity and, therefore, density, varies in a predictable manner with depth of burial. The depth-density relationship depends on lithology, but if sufficient density data are available, compaction curves can be generated for the basin of interest. Alternatively, the compaction curves supplied with HOTPOT can be used (Appendix I). The relationship between thickness and density for a given sedimentary layer is:

$$\frac{t_1}{t_2} = \frac{\rho_2 - \rho_w}{\rho_1 - \rho_w}$$

where: $t1$ = thickness at depth 1

$\rho 1$ = density at depth 1

t_2 = thickness at depth 2

ρ_2 = density at depth 2

ρ_w = density of pore fluid (1.03 g cm^{-3})

Thus if the thickness and depth of a sedimentary layer are known, its thickness at any other depth can be predicted. Backstripping is an iterative process, accomplished as follows:

a) Strip off the top layer of the stratigraphical sequence, move the remaining layers upwards and recompute their densities.

b) Recompute the layer thicknesses using the new densities.

c) Recompute the layer densities using the new thicknesses.

d) Repeat b) and c) until the change in thicknesses is negligible (this normally requires no more than about five iterations). Decompaction with the top layer removed is now complete.

e) Repeat a) to d) stripping off successive top layers until the entire sequence has been decompacted.

It is important to remember that the process of backstripping is a synthetic procedure designed to invert the real process of compaction. In the real world sediments do not actually decompact as they are uplifted; they tend to retain the porosities and thicknesses characteristic of their maximum depth of burial. The basic backstripping procedure, outlined above, has to be modified to take this into account when eroded layers are present. The compaction of layers *beneath* the eroded layers is determined by their maximum depth of burial; this may have occurred during burial beneath the eroded material rather than beneath the present-day overburden. On encountering eroded layers within a succession, HOTPOT computes and compares the relative thicknesses of eroded material and existing overburden. If the thickness of eroded material is the greater, the layers below are not decompacted. Any eroded layers are restored at the appropriate times in the basin history.

In basins with long and complex geological histories there may have been more than one episode of erosion. It may also be desirable, for stratigraphic reasons, to represent erosional episodes by several eroded layers. The algorithm which processes eroded layers operates recursively and can process models with multiple erosional episodes and with multiple layers in each episode.

An example of decompaction by backstripping is illustrated schematically in Fig. 2.2. Note how the deeper sedimentary layers become more compacted than the shallower ones. Note also the *sediment-loaded* subsidence path which defines the subsidence history of the basement beneath the basin.

Thus decompaction of all the 1-D grid-node stratigraphical sequences produces a pseudo-3-D basin decompaction. Chronological calibration of the decompacted grid-node sequences generates a pseudo-3-D burial history of the basin.

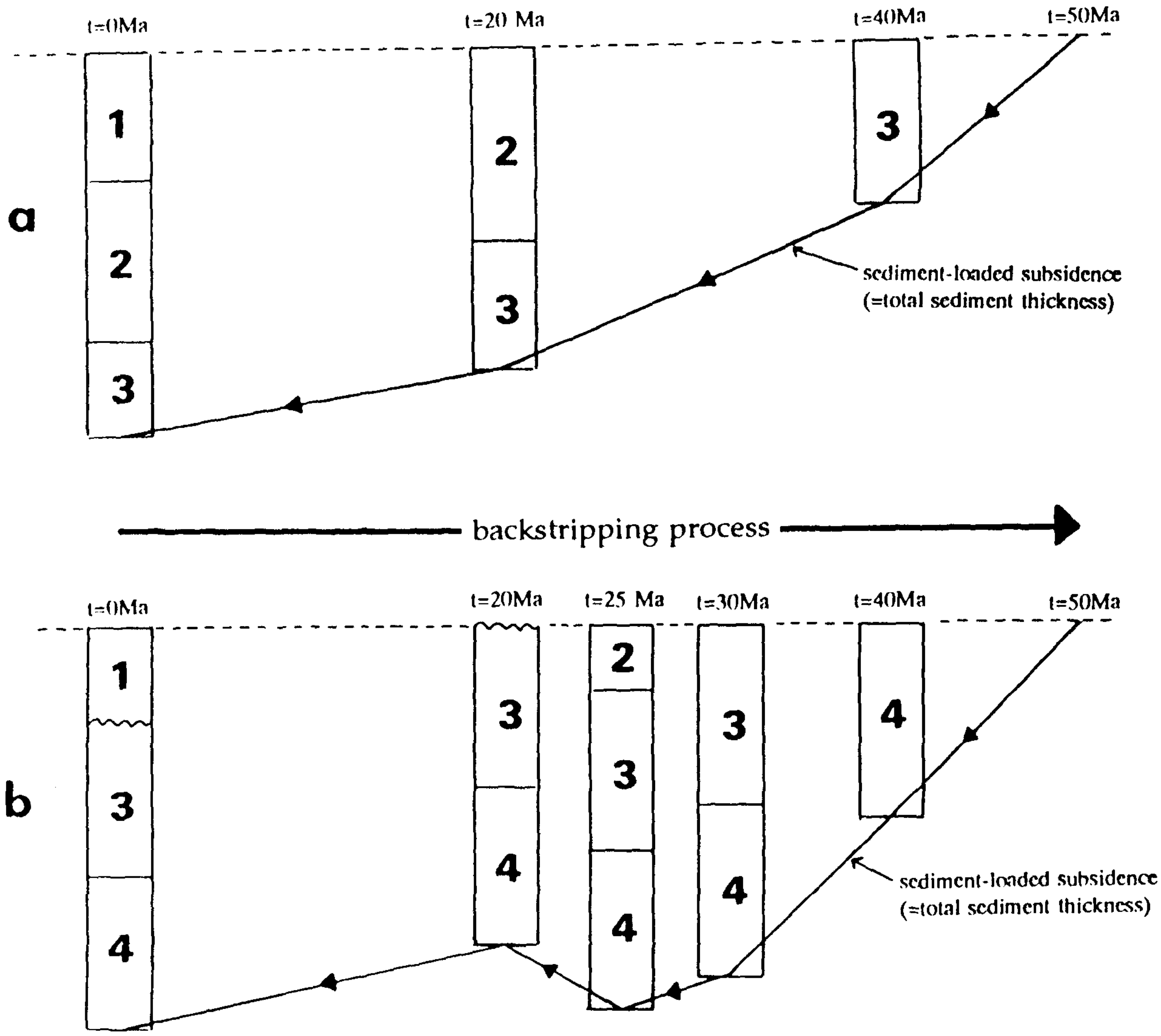


Figure 2.2: Decompaction of schematic stratigraphical sequences with a) no erosion; b) an erosional episode between 25 and 20 Ma. Note how the layer thicknesses decrease with burial, but do not increase again during erosional uplift.

Sediment-starved thicknesses (tectonic subsidence)

As a precursor to more sophisticated basin-modelling techniques (see Section 2.3 and Appendix IV) HotPot computes sediment-starved thicknesses (also known as *tectonic subsidence*).

The effect of sediment-loading is nullified at each grid-node by using the sediment loading equation:

$$S_w = \frac{S_s(\rho_m - \rho_s)}{(\rho_m - \rho_w)}$$

where: S_w = sediment-starved thickness at grid-node

S_s = sediment-loaded thickness at grid-node

ρ_m = density of mantle material (3.33 g cm^{-3})

ρ_w = density of sea-water (1.03 g cm^{-3})

ρ_s = bulk density of sedimentary column at grid-node

This has the effect of normalising the thickness and density of the sedimentary sequence deposited at the end of each stratigraphical interval to an equivalent depth of sea-water. The depth of water during deposition is accounted for by simply adding it to the sediment-starved thickness:

$$S_{wd} = S_w + h$$

where: S_{wd} = crustal-subsidence corrected for water depth

h = water-depth

HOTPOT does not include a facility to take into account changes in global sea-level, which are at present very poorly quantified.

By applying these procedures, HOTPOT produces sediment-starved subsidence values at each grid-node, and thus sediment-starved grids for the basin.

Output

Backstripped output from the program is as follows:

a) Colour-shaded gridded maps depicting present-day and palaeosediment thicknesses, sediment-starved thicknesses, layer and bulk densities.

b) 1-D grid-node extractions, depicting sediment-loaded and sediment-starved subsidence histories and layer burial histories.

2.2.2 Thermal calculation

Prior to the thermal calculation proper, HOTPOT has the facility to merge the stratigraphical sequences with the auxiliary thermal conductivity *vs.* depth data. This allocates realistic thermal conductivities to the present-day and decompacted stratigraphical layers at each grid-node.

The thermal calculation assumes simple vertical conductive heat transfer in the basin, with heat input from below. Heat production within the basin sediments is assumed to be negligible, i.e. heatflow at the bottom of the basin is equal to heatflow at the surface (or seabed).

Thus, at each grid-node:

$$Q = k \cdot \frac{dT}{dz}$$

where: Q = heatflow

k = thermal conductivity

T = temperature

z = depth

Therefore:

$$\int_{T_0}^{T_z} dt = Q\int_0^z \frac{1}{k} dz$$

where: T_z = temperature at depth z

T_0 = temperature at depth = 0 (surface or seabed)

Therefore:

$$T_z = T_0 + Q\int_0^z \frac{1}{k}\, dz$$

For a basin with N layers, i^{th} layer of thickness Δz_i and thermal conductivity k_i, the integral simplifies to the summation:

$$T_N = T_0 + Q\sum_{i=1}^{N}\frac{\Delta z_i}{k_i}$$

Incorporating time variable heatflow Q(t), the subsurface temperature at each grid-node varies with time, and can be described by the expression:

$$T_N(t) = T_0(t) + Q(t)\sum_{i=1}^{N}\frac{\Delta z_i}{k_i}$$

where: $T_N(t)$ = temperature at base of N^{th} layer at time *t*

$T_0(t)$ = surface or seabed temperature at time *t*

$Q(t)$ = heatflow at time *t*

Δz_i = thickness of i^{th} time-slice layer

k_i = thermal conductivity of i^{th} time-slice layer

HotPot utilises this summation in the computation of the thermal results, giving output as follows:

a) Colour-shaded gridded maps, depicting present-day and palaeotemperatures, and layer thermal conductivities.

b) 1-D grid-node extractions depicting layer thermal histories.

2.3 Prediction of palaeoheatflow

As indicated above, HotPot has the facility to incorporate time-variable heatflow into the thermal calculation. Present-day heatflow values can be measured directly, but estimation of palaeoheatflow is more difficult, requiring some knowledge of the mechanisms of basin formation.

Sedimentary basins fall into many different categories, depending upon their mode of development (Fig. 2.3). World-wide however, the large majority of hydrocarbon-bearing basins, can be classed as continental extensional basins. These basins form in response to tensional forces resulting from destructive plate-margin processes (Fig. 2.4). The basins can form both in continental interiors or close to the continental margin, for example in a back-arc environment.

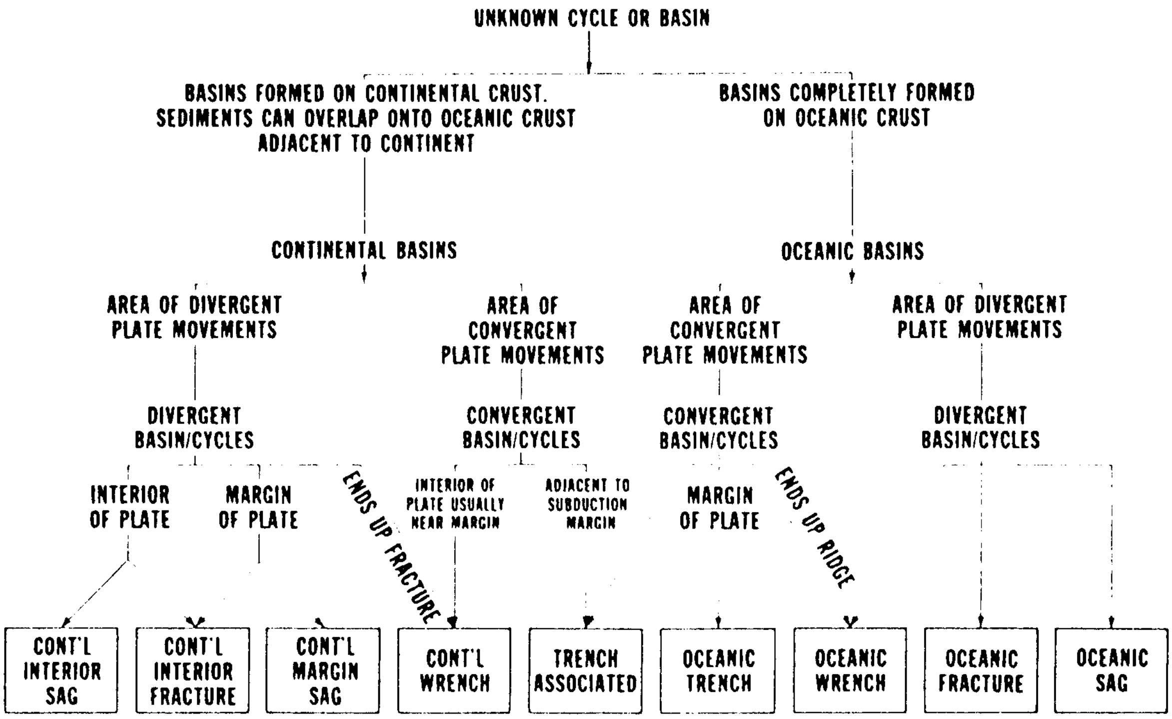


Figure 2.3: Global basin classification system (after Kingston *et al.* 1983)

Appendix IV gives notes on how palaeoheatflow may be predicted on a theoretical basis assuming uniform lithospheric extension. Other methods of estimating palaeoheatflow may include vitrinite reflectance data, spore coloration, apatite fission-track analysis, etc. Ultimately, the means by which palaeoheatflow is estimated is up to the individual user.

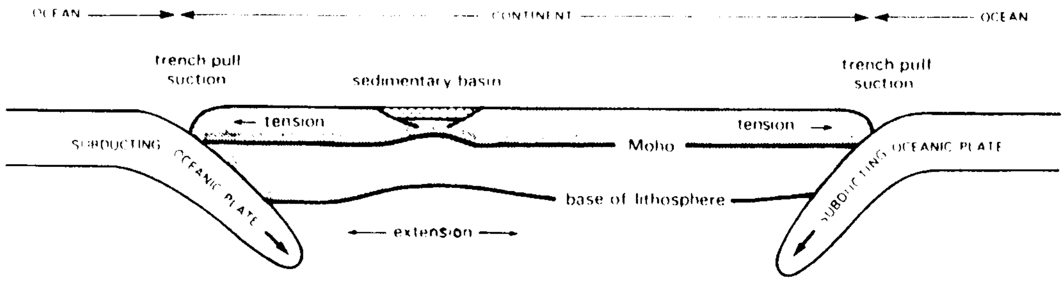


Figure 2.4: Schematic diagram to illustrate extension of the lithospheric plate (after Bott 1982)

2.4 HOTPOT program usage cycle

Whilst the Windows user interface allows flexibility in the way that tasks are accomplished and the order in which they are done, certain restrictions are imposed by the nature of the modelling process. Briefly:

- The area of interest must be defined before layer information can be added, because it is needed for the gridding process.

- The decompaction calculation can only be performed when all layers have been defined and the density *vs.* depth table has been loaded, because both data sets are needed for the calculation.

- Once the decompaction calculation has been performed, the layer structure cannot be altered.

- Thermal property values must be assigned to layers and time calibration points before the geothermal calculation can be performed, because these data are needed for the calculation.

- A thermal conductivity *vs.* depth table must be loaded before the optional depth-variable thermal conductivity values can be used in the geothermal calculation.

- Heatflow data must be gridded and the grids attached to time calibration points before the optional gridded heatflow data can be used in the geothermal calculation.

The user interface is designed to control the order of events by enabling or disabling selectable activities according to the above rules.

- The thermal parameters may be altered after the thermal calculation has been performed. However, this invalidates the results of the calculation, so it must be performed again to bring the database up to date.

This is the key to the usage cycle:

1 Enter layer data

2 Decompact to reconstruct basin history

3 Set thermal parameters

4 Compute thermal model

5 Display, examine and review model data

6 Modify thermal parameters and repeat from step 4

SECTION 3

Installing HOTPOT

3.1 System requirements

Version 3.0 of the BGS basin modelling software, HOTPOT, is designed to be used on an IBM PC or PS/2 or compatible microcomputer with the following specification:

- either an 80386 or 80486 processor
- at least 2Mb of RAM
- a hard disk with at least 5Mb free space
- a 3.5 inch 1.44Mb diskette (required for software installation only)
- a VGA colour graphics display
- a mouse and a keyboard
- a maths coprocessor is not required but, where available, will provide a significant increase in program performance
- MS-DOS or PC-DOS version 4 (or above) operating system
- Microsoft Windows version 3.0 (or above) graphical user interface system

3.2 User requirements

It is assumed that the user has a basic familiarity with the Windows user interface and its terminology and knows how to:

- manipulate displayed windows using the mouse-pointer
- manipulate dialogue boxes and their controls using the mouse-pointer and keyboard
- copy files using File Manager
- install third-party software using the Program Manager
- start applications using either the Program Manager or the File Manager

These topics are described by the first six chapters of the *Microsoft Windows User's Guide* (part of the documentation supplied with the Windows software) and should be familiar to anybody who has used applications such as Windows Write and Windows Paintbrush.

3.3 Document conventions

In this document the following printing styles are used for the stated purposes:

Bold Helvetica type	Text or prompts in windows or dialogues
SMALL CAPITALS TYPE	Windows key sequences

The following verbs are used with specific meaning in describing the operation of Windows

software:

to choose means to pick an item that begins an action

to select means to mark an item for use in a future action

This table shows how these terms relate to the Windows controls used in the HOTPOT program.

	Mouse		Keyboard	
Control type	**Choose**	**Select**	**Choose**	**Select**
Menu (drop-down from menu bar)	Point to and single-click		Press ALT + initial letter keys together	
Option in menu	Point to and single-click		Press initial letter key	
Button	Point to and single-click		Press ALT + initial letter keys together Press RETURN for **Ok** button Press ESC for **Cancel** button	
Radio button and check box		Point to and single-click		Press ALT + initial letter keys together
List box				Press ALT + initial letter keys together
Item in list box	Point to and double-click	Point to and single-click	Locate with up and down arrow keys then press RETURN	Locate with up and down arrow keys then press SPACEBAR
Text in edit box		Point to and single-click		Press ALT + initial letter keys together

3.4 Windows operating modes

A comprehensive discussion of Windows operating modes is beyond the scope of this Manual. (The interested reader may refer to either Chapters 1 & 13 of the *Windows User's Guide* [for Windows 3.0 users] or Chapter 1 of *Getting started with Microsoft Windows* and Chapter 14 of the *Windows User's Guide* [for Windows 3.1 users] for more information.)

Briefly, Windows has either two or three operating modes:

Real: used mainly for compatibility with old Windows 2.0 applications and on small PC systems with 1Mb or less of RAM (Windows 3.0 only)

Standard: used where virtual memory is not required (Windows 3.0 and 3.1)

386 Enhanced: used where virtual memory is required on PC systems which have an 80386SX, 80386DX, 80486SX, 80486DX or 80486DX2 processor (Windows 3.0 and 3.1)

Although the HOTPOT software will work in any Windows mode, it is designed for use with Windows in 386 Enhanced mode, so that the Windows virtual memory manager is available. This is

SECTION 4

HOTPOT Tutorial

4.1 The tutorial data set

4.1.1 Primary data

In the tutorial, an imaginary sedimentary basin is modelled. The basin-fill comprises three stratigraphical units. Isopach contour maps of these units are illustrated in Figures 4.1, 4.2 and 4.3. The oldest unit, the Tollerton Formation, was deposited between 25 and 20 Ma ago and comprises the *syn-rift* part of the basin-fill, with sediments restricted to local fault-bounded basins (Fig. 4.3). Subsequent units form the *post-rift* sequence and are unfaulted. The Ruddington Formation (Fig. 4.2) was deposited between 20 and 10 Ma, and the Keyworth Formation (Fig. 4.1) between 10 Ma and the present. Layer information for the three units is summarised in Table 4.1.

Formation name	Lithology	Age at base of layer	Water depth
Keyworth Formation	sandstone	10 ma	0 m
Ruddington Formation	50% sandstone 50% limestone	20 Ma	10 m
Tollerton Formation	mudstone/siltstone	25 Ma	30 m

Table 4.1

Figures 4.1, 4.2 and 4.3 also show the digitised contour data (digitised with latitude and longitude increments of 0.05°) derived from the isopach maps. Note that the gridding algorithm within HOTPOT cannot deal with faults, it is necessary to treat these features as steep gradients (Fig. 4.3).

Tutorial Model 1 is a simple run of the program using data prepared in advance. It is designed to give you an overview of the program's capabilities and features, and to familiarise you with the program data displays and their use. In Tutorial Models 2 and 3 you will do much of the data input yourself, as you will do when you use your own data sets with HOTPOT.

In Model 2 you will compare two data sets for the Ruddington Formation. You will find that the original Ruddington Formation isopach contours (Fig. 4.2a) are too widely spaced to permit gridding with a reasonable search radius. You will then use a second data set which has additional *control contours*. These were constructed by interpolation between the original contours, digitised and appended to the original dataset (Fig. 4.2b). This part of Model 2 illustrates a common problem, that you may experience when you use your own data with HOTPOT, and demonstrates its solution.

In parts of the backstripping process, HOTPOT masks all layer grids down to the data area common to all the grids, with null nodes generated elsewhere. The sedimentary area of the Ruddington and Tollerton Formations is less than the sedimentary area of the Keyworth Formation. In order that HOTPOT realises that areas outside the zero isopach contour represent a known absence of sediment,

rather than just an absence of data, it is necessary to plot additional zero contours, such that the contoured areas of all the layers fill the known area (in this case the limits of the Keyworth Formation). These zero-value *anti-masking contours* are spaced at about the same distance as the real contours and are digitised as part of the layer data file. They are not illustrated in Figs. 4.2 and 4.3, because their detailed shape is arbitrary, but the area within which they occur is marked by the dashed line.

Model 1 assumes the simple case of constant heatflow through time. Model 2 assumes a spatial variation of present-day heatflow which is expressed as a heatflow contour (mW m^{-2}) map (Fig. 4.4). This is digitised as above.

Model 3 of the Tutorial incorporates an episode of erosion. The topmost subdivision of the Ruddington Formation, the Bingham Member, was deposited from 14 to 12 Ma and then eroded between 12 and 10 Ma. The eroded layer is expressed as an isopach contour map (Fig. 4.5), digitised as the above maps. The information for the eroded layer is summarised in Table 4.2.

Formation name	Lithology	Age at base of layer	Water depth	Age eroded
Bingham Member	50% sandstone 50% limestone	14 Ma	10 m	12 Ma

Table 4.2

After installation (section 3.6) the primary data should be stored on the disk as follows:

Keyworth Fm layer information .... c:\tutorial\keyworth.lay

Keyworth Fm digitised isopachs .... c:\tutorial\keyworth.iso

Ruddington Fm layer information (original).......................... c:\tutorial\ruddingo.lay

Ruddington Fm digitised isopachs (original).......................... c:\tutorial\ruddingo.iso

Ruddington Fm layer information (additional)...................... c:\tutorial\ruddinga.lay

Ruddington Fm digitised isopachs (additional)...................... c:\tutorial\ruddinga.iso

Tollerton Fm layer information.. c:\tutorial\toller.lay

Tollerton Fm digitised isopachs.. c:\tutorial\toller.iso

Bingham Member digitised isopachs .... c:\tutorial\bingham.iso

Heatflow contours .... c:\tutorial\heatflow.iso

4.1.2 Auxiliary data

The following auxiliary data files are stored on the disk:

Depth-Density data.. c:\tutorial\malay.ddt

Depth-Thermal Conductivity data .... c:\tutorial\malay.dkt

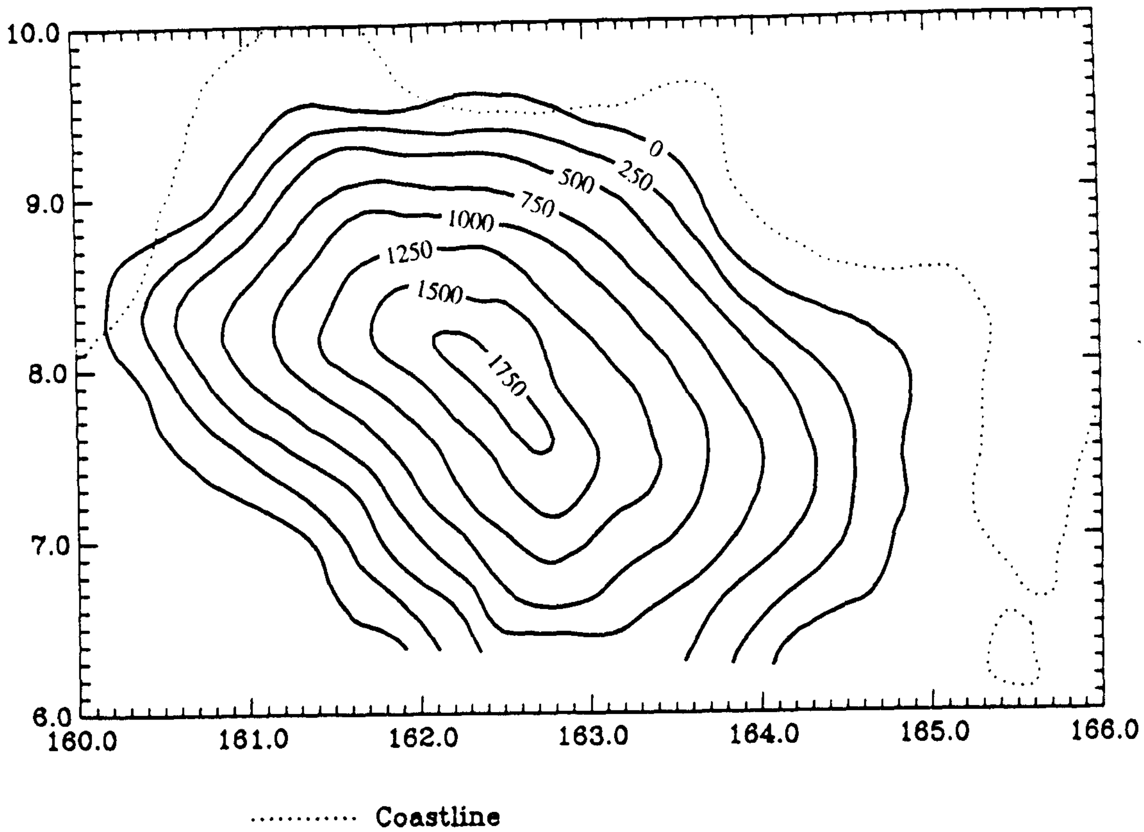
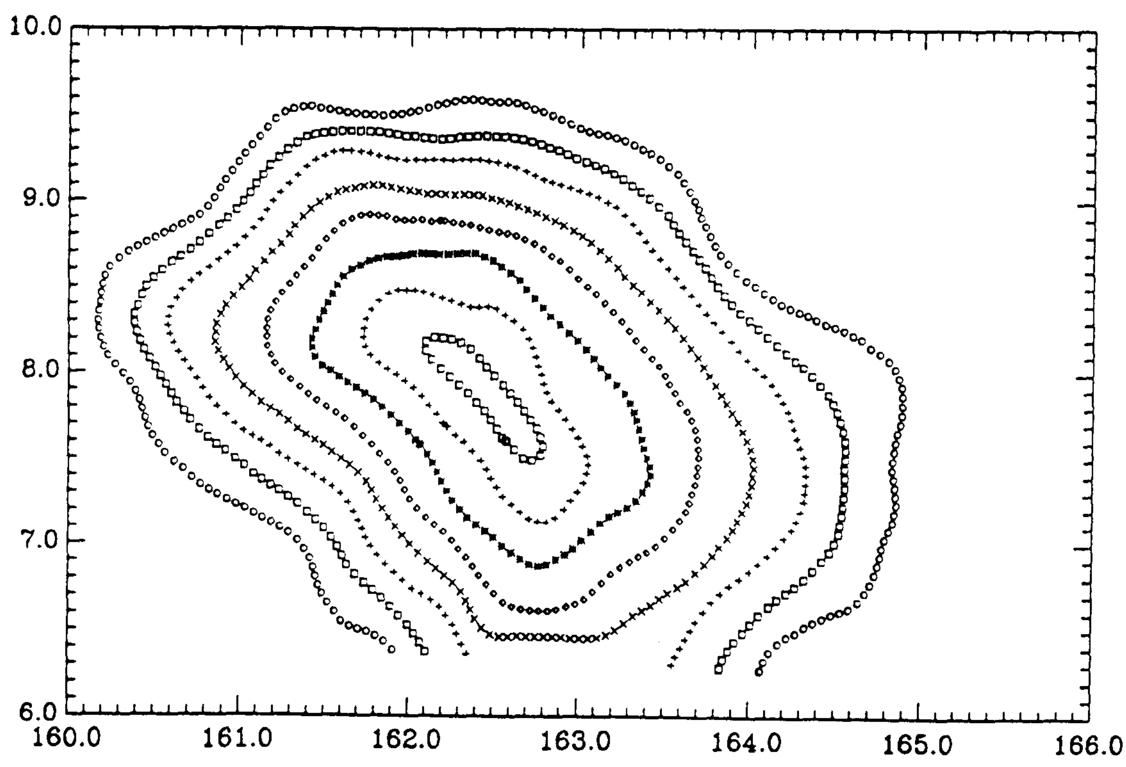


Figure 4.1: Keyworth Formation

Top: Isopach map (contours in metres)

Bottom: Digitised isopach data (file keyworth.iso)



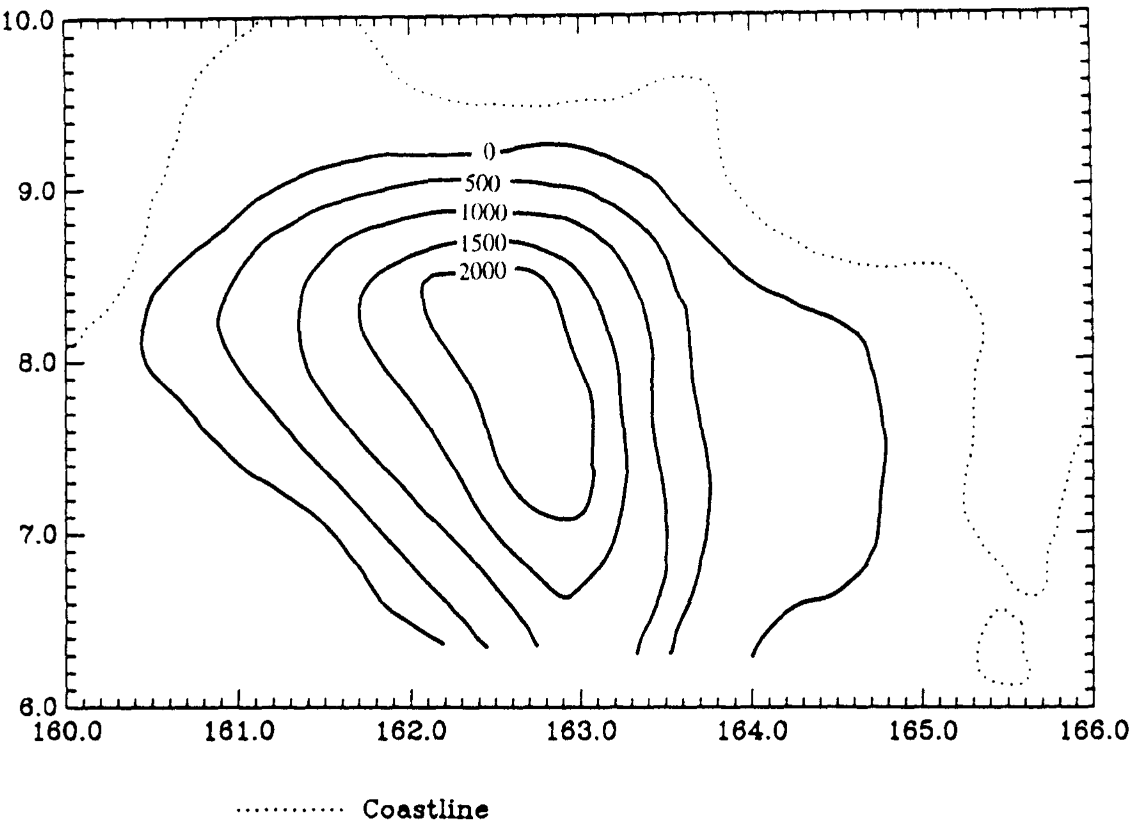
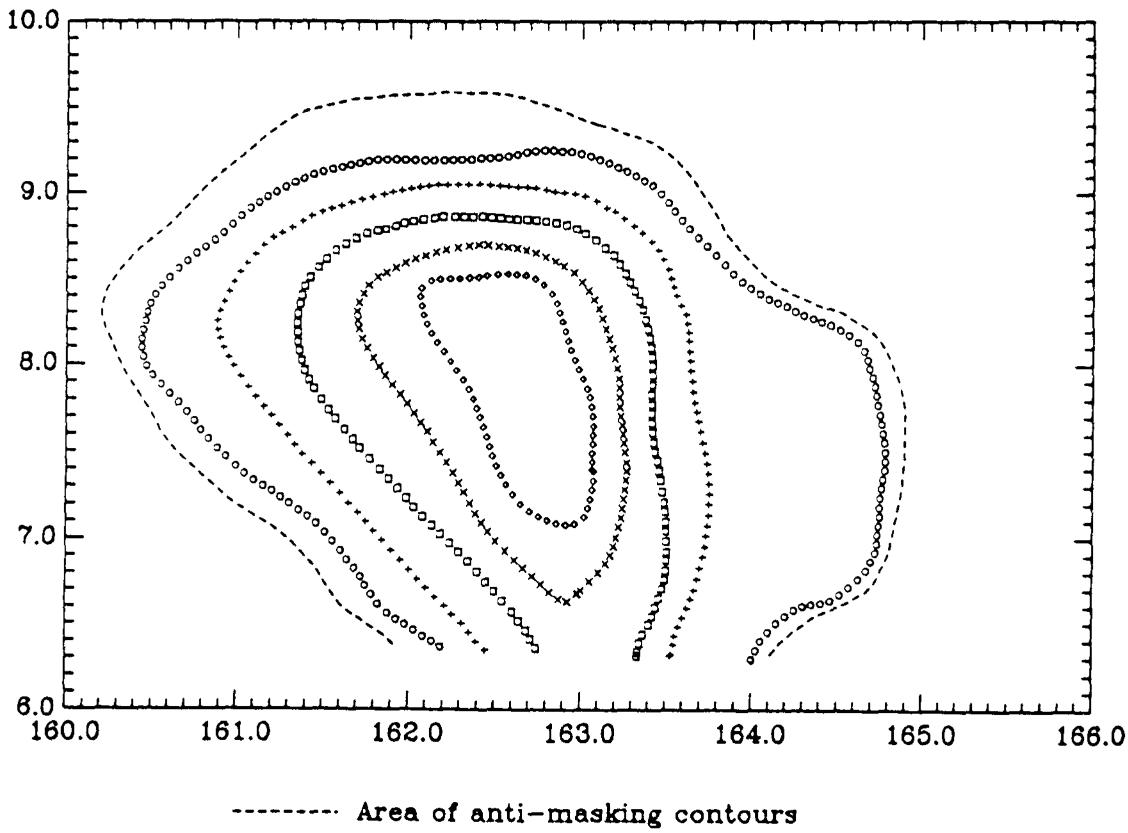


Figure 4.2a: Ruddington Formation

Top: Original isopach map (contours in metres)

Bottom: Digitised original isopach data (file ruddingo.iso)



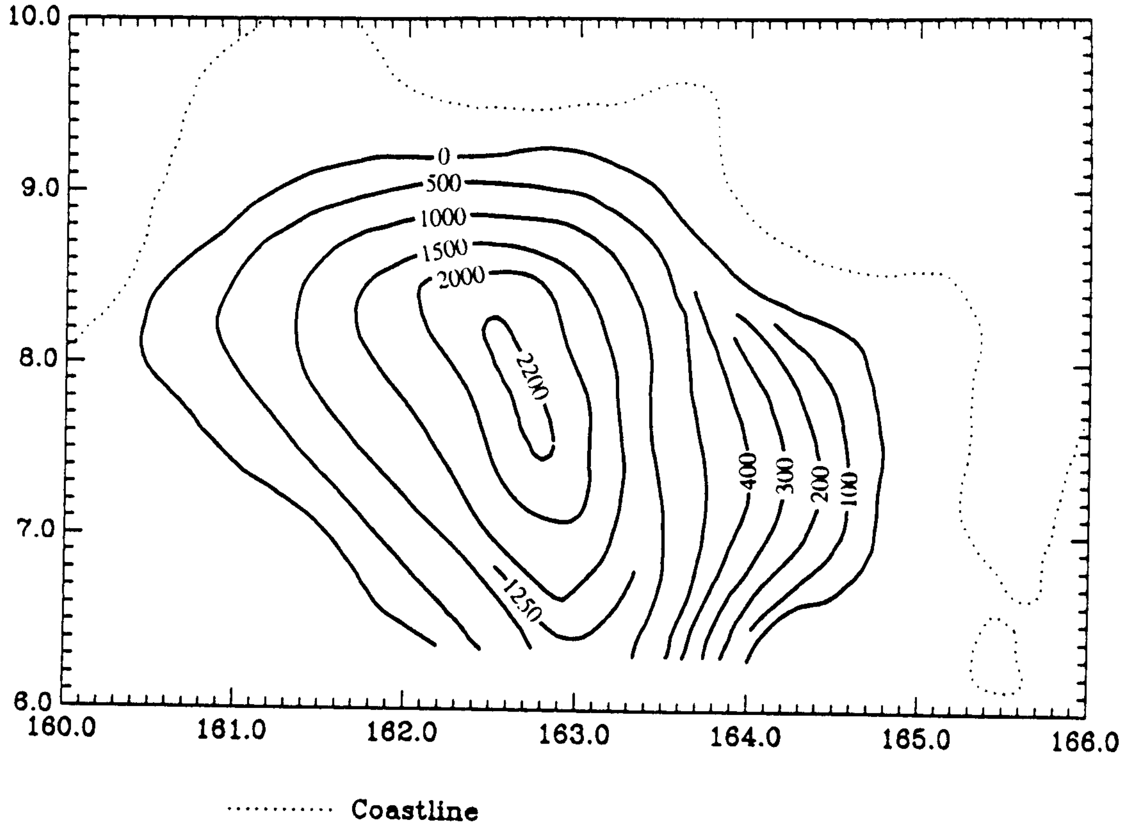
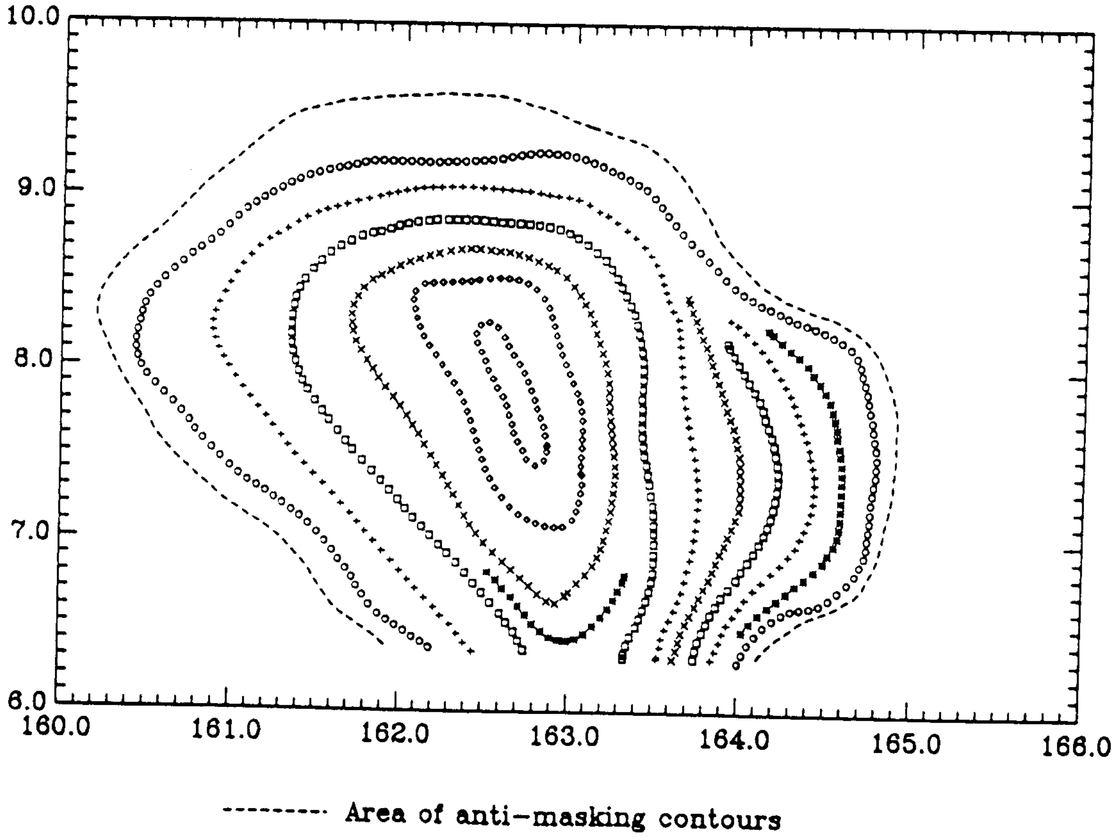


Figure 4.2b: Ruddington Formation

Top: Isopach map with additional *control contours* (contour values in metres)

Bottom: Digitised isopach data (file ruddinga.iso)



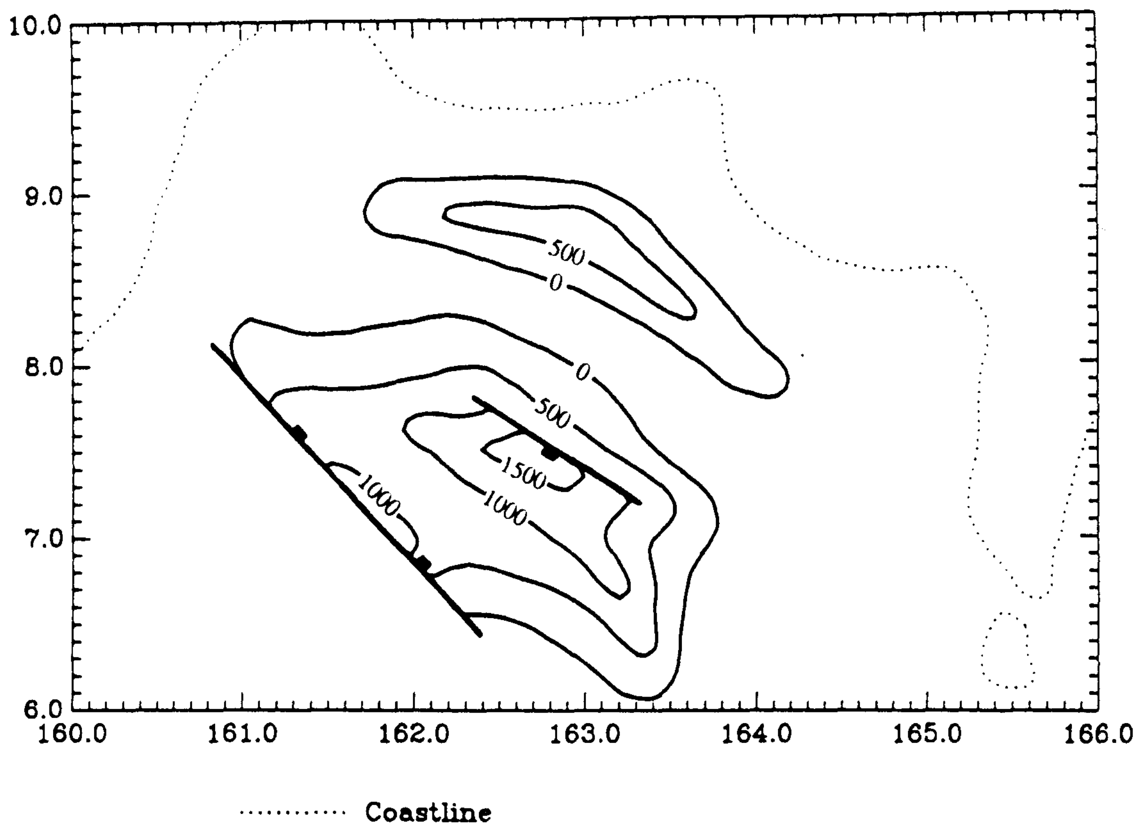
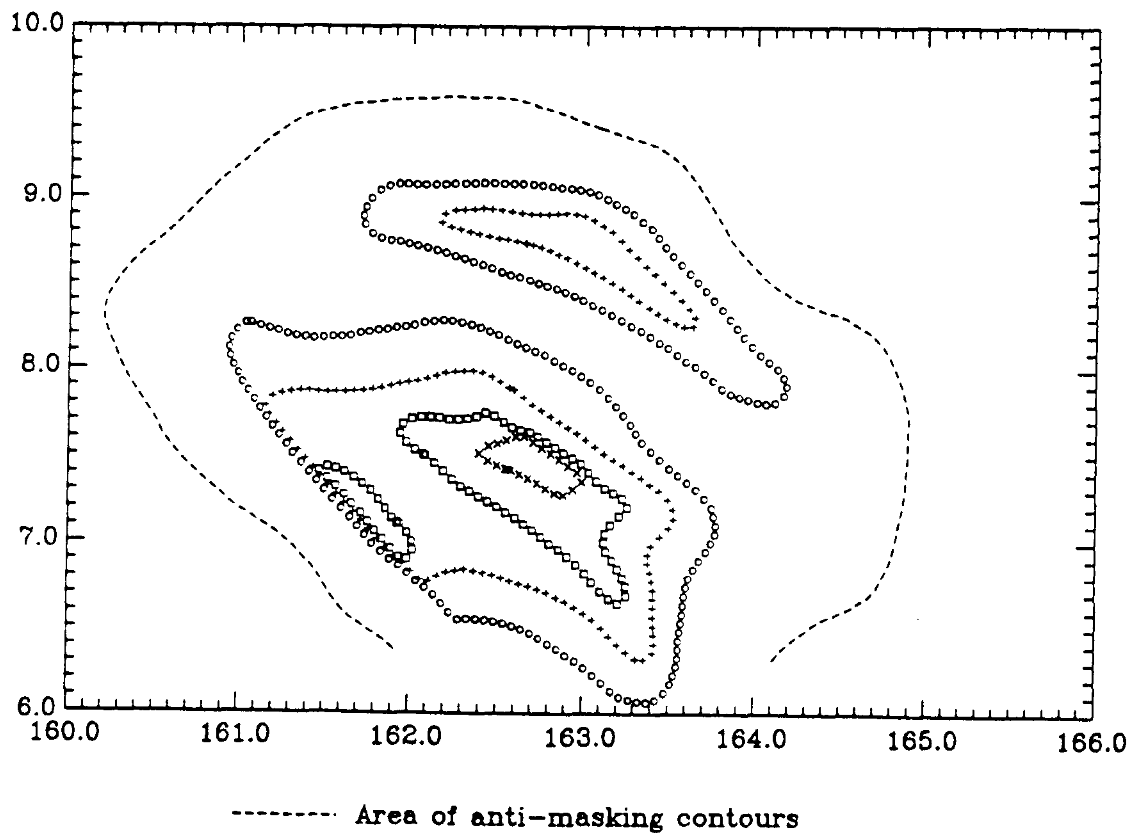


Figure 4.3: Tollerton Formation

Top: Isopach map (contour values in metres)

Bottom: Digitised isopach data (file toller.iso)



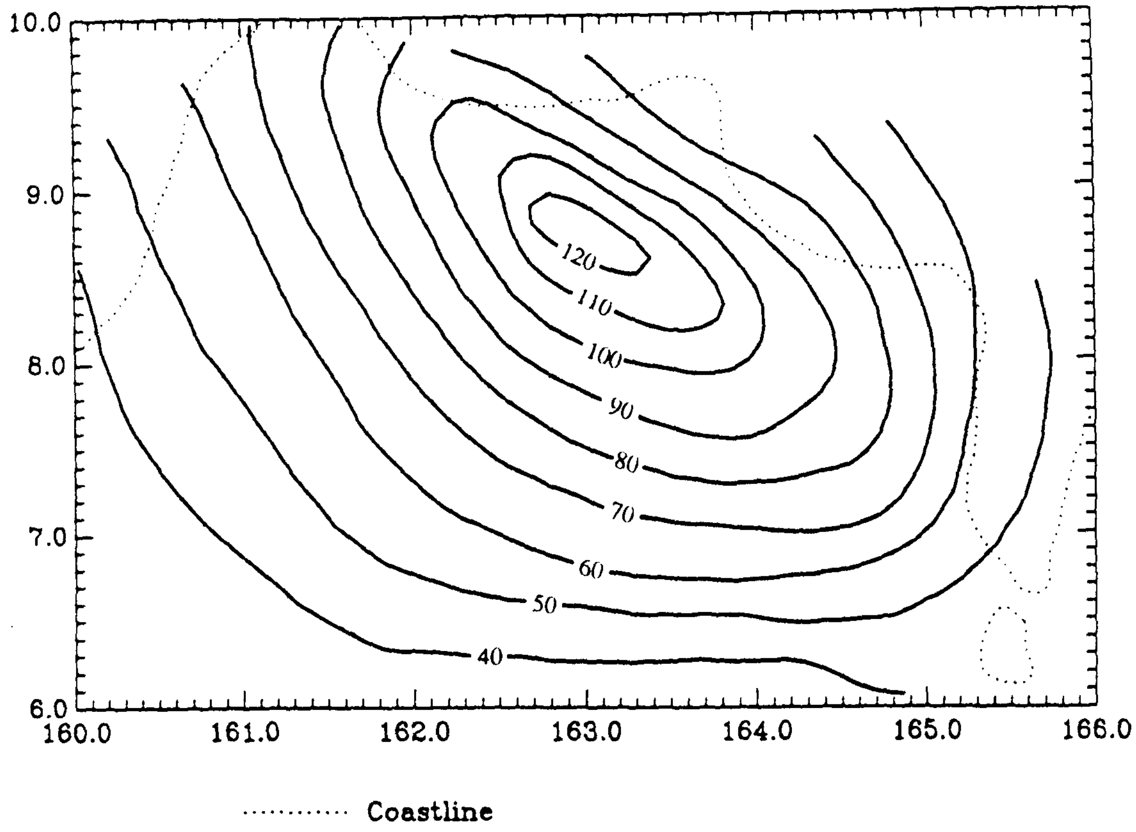
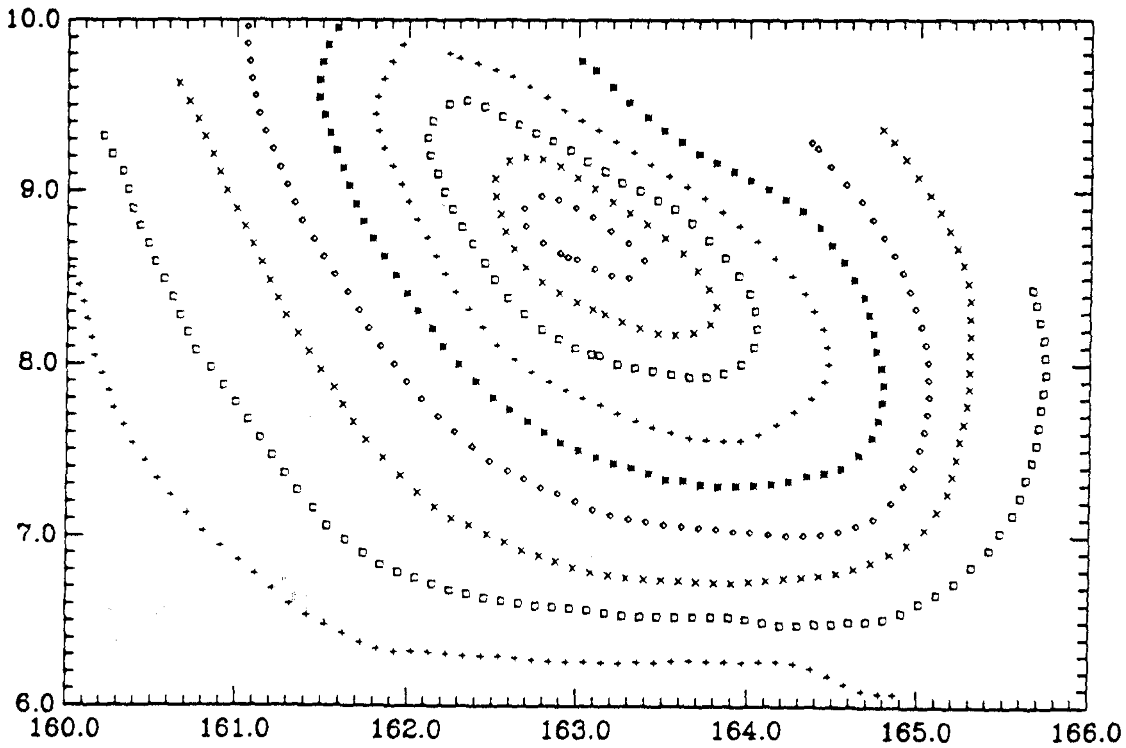


Figure 4.4: Present-day heatflow map

Top: Heatflow contour map (contour values in mW m^{-2})

Bottom: digitised contour data (file heatflow.iso)



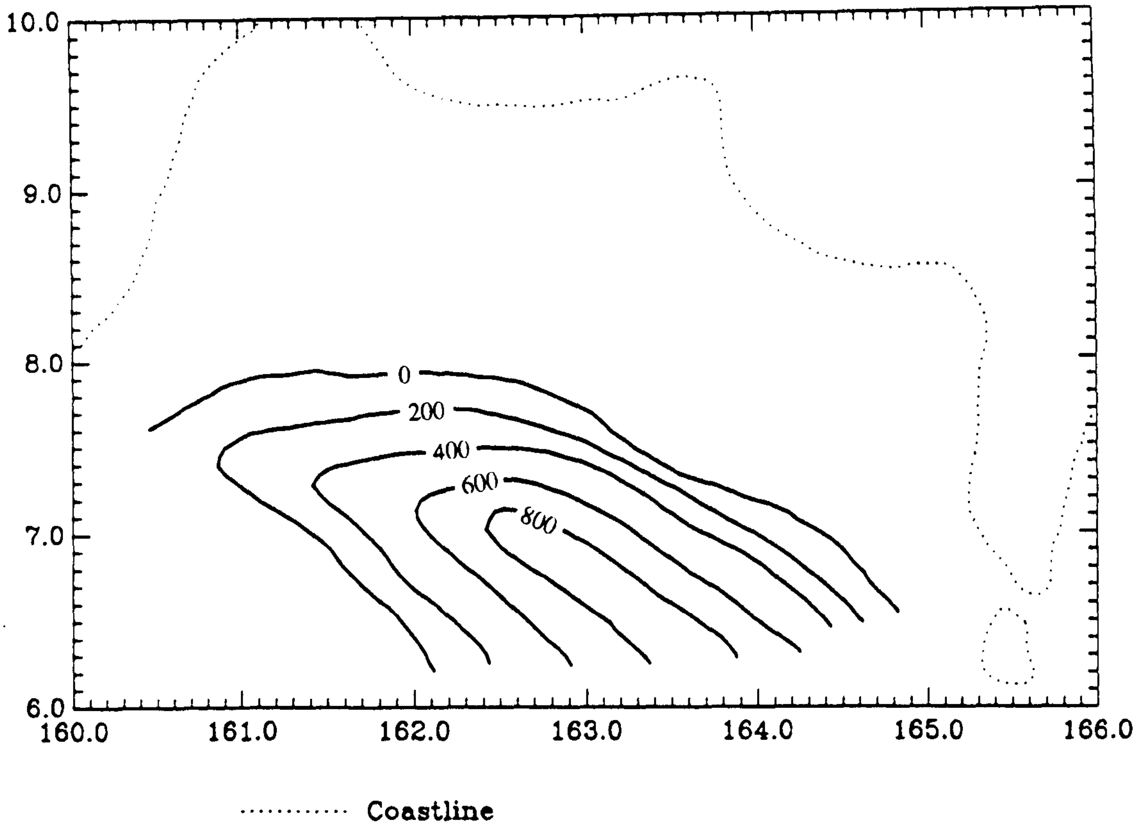
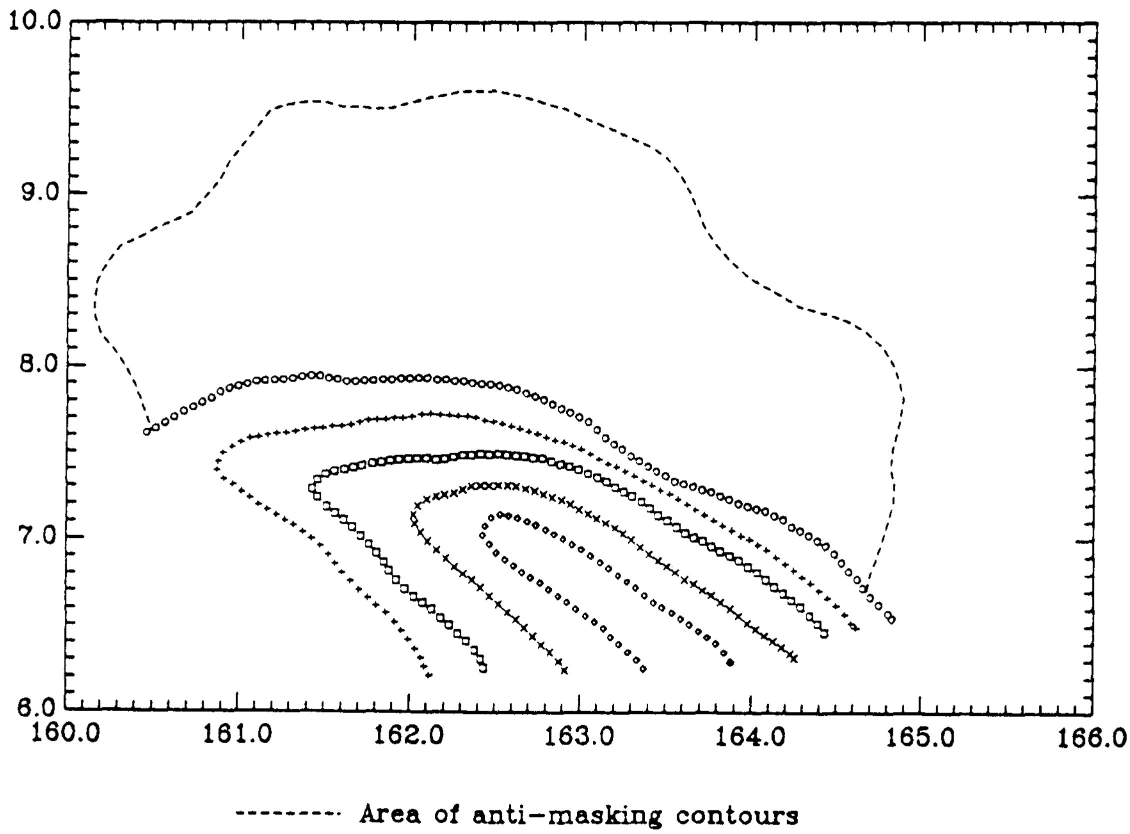


Figure 4.5: Bingham Member (eroded topmost part of Ruddington Formation)
Top: Isopach map (contour values in metres)
Bottom: digitised isopach data (file bingham.iso)



4.1.3 Optional data

The area of interest (AoI) co-ordinates and grid spacing can be input to HOTPOT by the user, but for convenience are also stored in the file c:\tutorial\tutorial.aoi

Map annotation data, in the form of a digitised coastline, are stored in the file c:\tutorial\coast.dat

4.2 Tutorial Model 1

This is a basic model, with no erosion and single-value constant heatflow. The modelling session is designed to provide you with an overview of the HOTPOT program and makes use of prepared data files wherever possible.

4.2.1 Set the model title

Start the HOTPOT program using the method described in Section 3.7

You should have the HOTPOT Main Window on the screen.

Choose **Settings** menu

This drop-down menu is used to set the model parameters.

Choose **Title...** option

This opens the Set Title dialogue.

Type **Model 1** into the **Title** box, then choose **Ok** button (or press RETURN key)

This sets the model title, Fig. 4.6. The HOTPOT Main Window is redisplayed, with the new title shown on its caption bar.

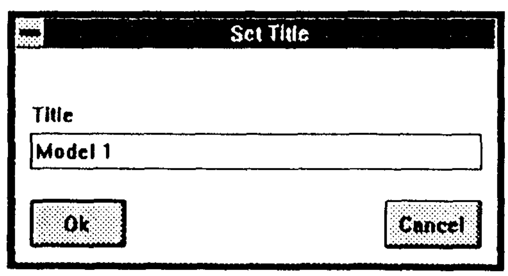


Figure 4.6

4.2.2 Define the area of interest

Choose **Settings** menu

Choose **Area of Interest...** option

This opens the area of interest (AoI) dialogue. The necessary data can be either entered directly from the keyboard or, as in this Tutorial, loaded from a previously saved file.

Choose **Load...** button

This enables previously saved AoI co-ordinates and grid spacings to be loaded into HOTPOT. A file selector dialogue opens.

Choose **[..]** from **Directories** list

This is a list of current directories. [..] is the directory one level above the current directory in the hierarchy. The lists in the Files and Directories list boxes will be updated.

Choose **[tutorial]** from **Directories** list

The selector switches the current Path *to the* c:\tutorial *directory and lists its files in the* Files *list box.*

Choose **tutorial.aoi** from **Files** list

The file selector dialogue closes and the AoI co-ordinates are loaded from file tutorial.aoi *and displayed in the boxes of the AoI dialogue. (Fig 4.7).*

Choose **Ok** button

The AoI dialogue closes and the area of interest specification is accepted. You may notice, next time you use the **Settings** *drop-down menu, that the* Area of interest... *option is check-marked to indicate that it is set.*

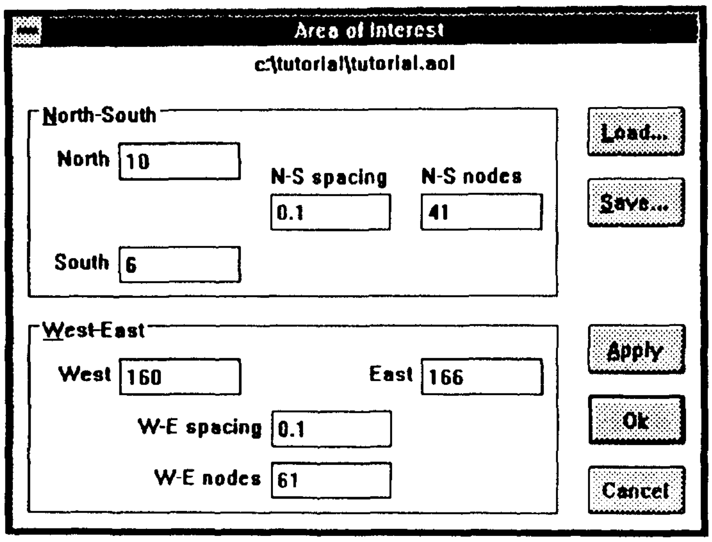


Figure 4.7

4.2.3 Load and grid the layer isopach data

It is best to load the layer data in formation age order, starting with the youngest.

Load the Keyworth Formation data

Choose **File** menu

This drop-down menu is used to control data input and output operations.

Choose **Layer...** option

The layer information dialogue opens. The necessary lithological, age and water depth data can be either entered directly from the keyboard or, as in this Tutorial, loaded from a previously saved file.

Choose **Load...** button

This enables previously saved layer information to be loaded back into HOTPOT. A file selector dialogue opens.

Choose **keyworth.lay** from **Files** list

Layer information is loaded from file keyworth.lay. *The layer information dialogue is redisplayed, with the information shown (Fig. 4.8, cf. Table 4.1). This information also includes a reference to the digitised isopach data file* keyworth.iso.

To confirm this file reference: Choose **Data files...** button	*A file-list dialogue opens. You should see the filename c:\tutorial\keyworth.iso in the Selected files list box at the top of the dialogue, Fig. 4.9.*

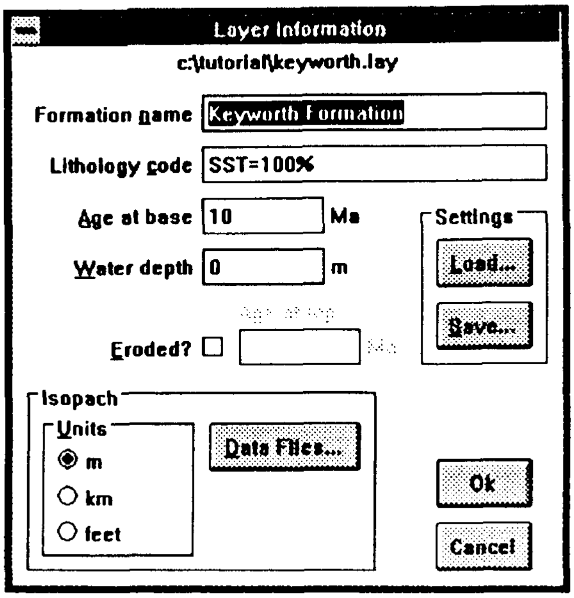


Figure 4.8

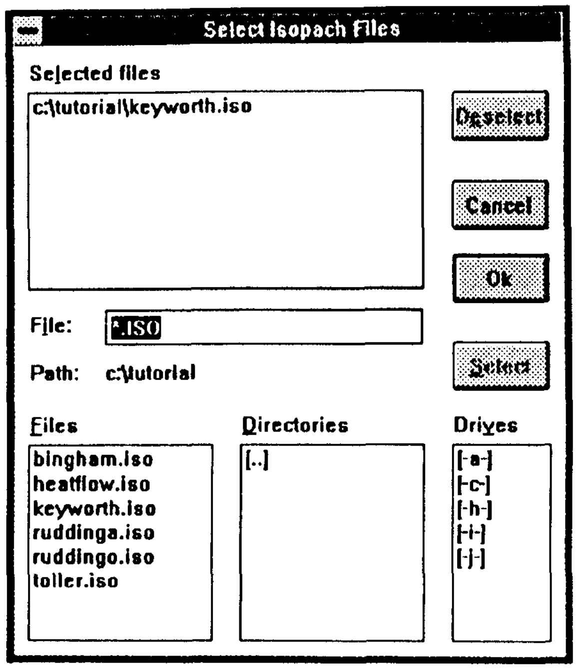


Figure 4.9

Choose **Cancel** button	*The file-list dialogue closes without change. The layer information dialogue is redisplayed.*
Choose **Ok** button	*The layer information dialogue closes and the gridding window opens as a full-screen window. The program is ready to grid the digitised Keyworth Fm isopach data.*
Choose **Grid...** button	*The gridding search radius dialogue opens in the top left of the gridding window. The search radius controls the resolution of the weighted-mean type gridding algorithm used in HotPot.*
Type **0.16** into **Radius** box	*A gridding search radius of 0.16° is chosen, Fig. 4.10. The choice of search radius is important and will be reviewed in detail in Model 2.*

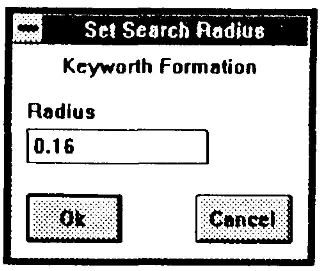


Figure 4.10

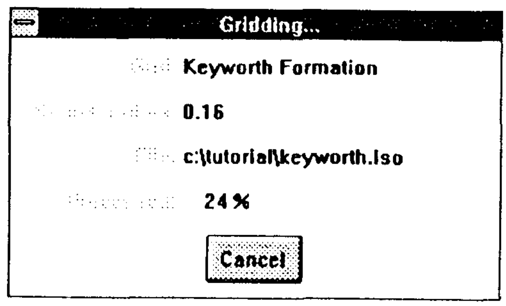


Figure 4.11

Choose **Ok** button (or press RETURN key)

Gridding starts and a progress dialogue opens in the top-left of the gridding window. This shows information about the data being gridded and the percentage completed, Fig. 4.11.

When gridding is complete, a grid map is shown in the gridding window, Fig. 4.12.

Choose **Accept** button

The grid is accepted, the gridding window closed and the HOTPOT main window redisplayed.

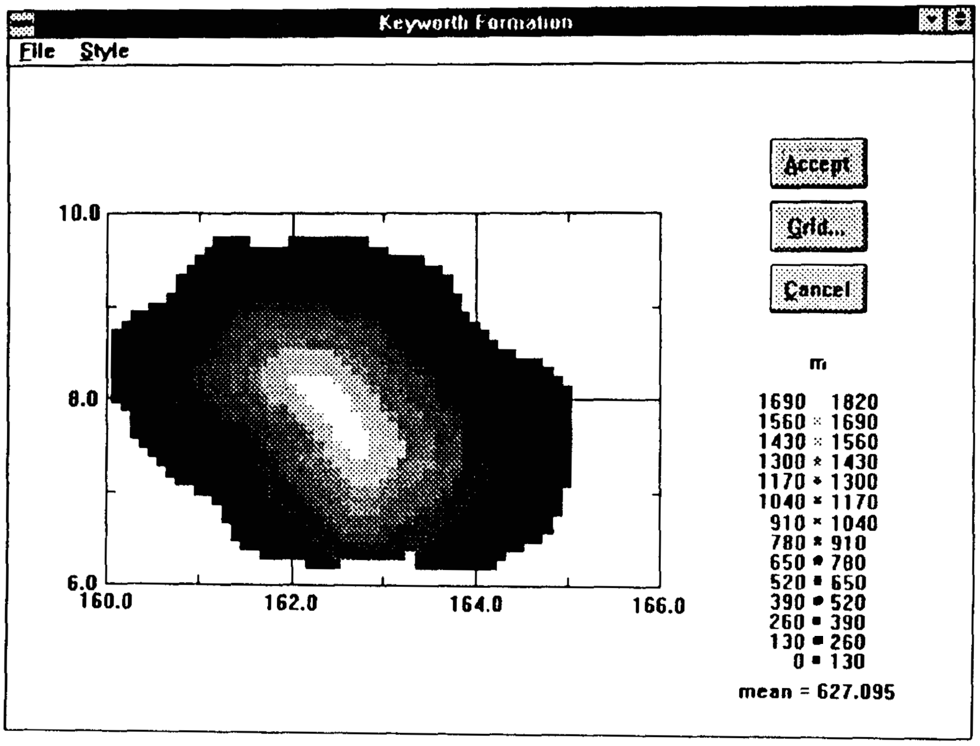


Figure 4.12

The HOTPOT Main Window now shows a rectangular, cyan coloured Keyworth Formation button at the top left, Fig. 4.13. This indicates that the Keyworth Formation layer information and isopach grid have been stored for later use.

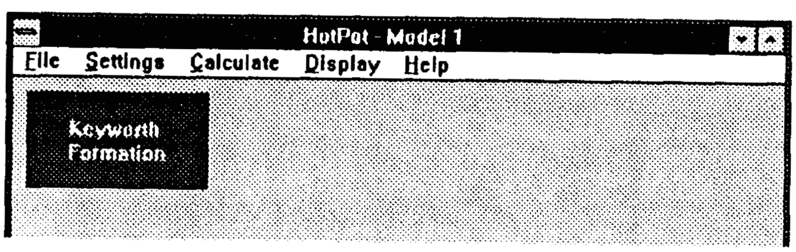


Figure 4.13

Load the Ruddington Formation data

Choose **File** menu

Choose **Layer...** option — *The layer information dialogue opens.*

Choose **Load...** button — *A file selector dialogue opens.*

Choose **ruddinga.lay** from **Files** list — *Layer information is loaded from the file* **ruddinga.lay**. *The layer information dialogue is redisplayed with the information shown. This also includes a reference to the digitised isopach file* *ruddinga.iso.*

Choose **Ok** button — *The gridding window opens. The program is ready to grid the digitised Ruddington Fm isopach data.*

Choose **Grid...** button

Type **0.19** into **Radius** box, then choose **Ok** button (or press RETURN key) — *The program grids the isopach data with a search radius of 0.19° A grid map is shown, Fig. 4.14.*

Choose **Accept** button — *The grid is accepted, the gridding window closed and the HOTPOT main window redisplayed.*

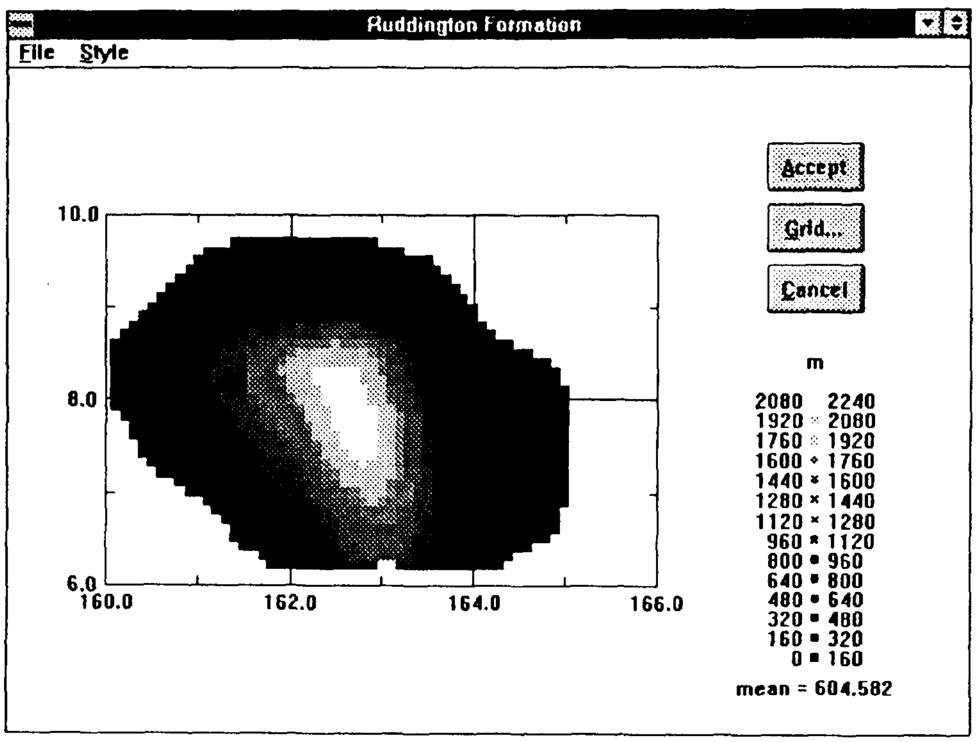


Figure 4.14

The HOTPOT main window display shows the Ruddington Formation button drawn below the Keyworth Formation button, in its correct stratigraphic position in the column (Fig. 4.15). Note that the Ruddington Formation button has its text shown in white while the Keyworth Formation button now has its in black. The white text indicates the selected layer. The last layer added is automatically selected.

Load the Tollerton Formation data

Choose **File** menu

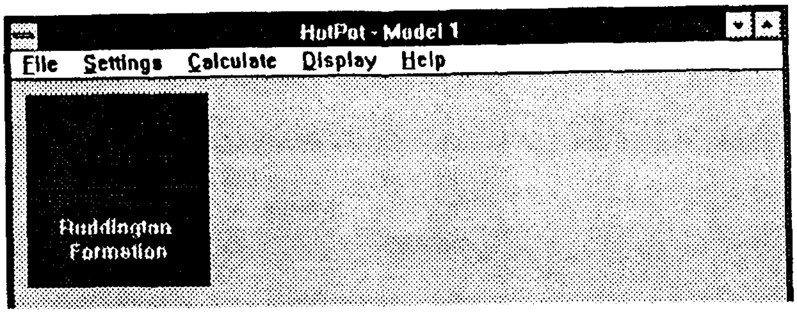


Figure 4.15

Choose **Layer...** option

Choose **Load...** button

Choose **toller.lay** from **Files** list

Layer information is loaded from file toller.lay. *The layer information dialogue is redisplayed with the information shown. This also includes a reference to the digitised isopach file* toller.iso.

Choose **Ok** button

The gridding window opens. The program is ready to grid the digitised Tollerton Fm isopach data.

Choose **Grid...** button

Type **0.19** into the **Radius** box, then choose **Ok** button (or press RETURN key)

The program grids the isopach data with a search radius of 0.19° and shows a grid map, Fig. 4.16. Note the large area of zero thickness nodes around the actual sedimentary-fill.

Choose **Accept** button

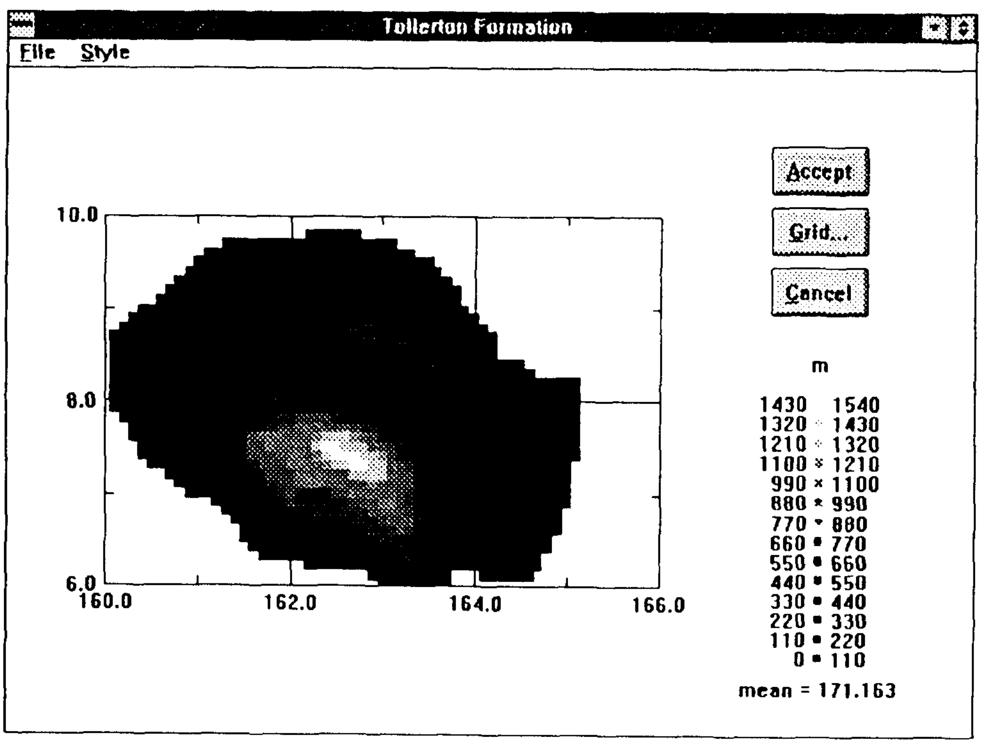


Figure 4.16

The HOTPOT main window shows the Keyworth Formation, Ruddington Formation and Tollerton Formation buttons displayed in a stratigraphic column (Fig. 4.17). All three model layers have been loaded and are ready for decompaction.

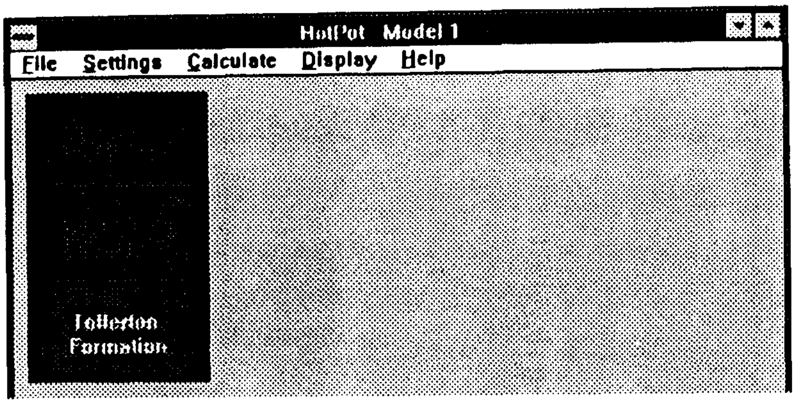


Figure 4.17

4.2.4 Load auxiliary depth/density data

Before decompaction, a table of density *vs.* depth data must be loaded from an auxiliary data file.

Choose **File** menu

Choose **Depth/Density...** option	*A file selector dialogue is displayed for you to select a depth/density file.*
Choose **malay.ddt** from **Files** list	*The depth/density information is loaded into the program and the HOTPOT Main Window is redisplayed.*

4.2.5 Decompaction by backstripping

HOTPOT now has the necessary layer, isopach and depth/density data and is ready to begin the backstripping and decompaction process.

Choose **Calculate** menu	*This drop-down menu contains the calculation options.*
Choose **Decompaction** option	*Individual depth/density curves are generated for each layer, based upon the mix of standard lithologies given in the layer information data. Diagnostic information on the backstripping and decompaction process is reported in a progress dialogue (Fig. 4.18). On completion, the HOTPOT Main Window is redisplayed, Fig. 4.19.*

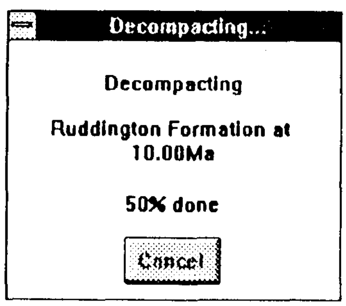


Figure 4.18

Two types of buttons are used, arranged as a series of stratigraphic columns, to illustrate graphically the stratigraphical evolution of the basin, Fig. 4.19. They show the present day basin sequence and the decompacted sequences at stages in the basin history from 25 million years ago to the present. The yellow button, at the top of each column, shows the age of the column in millions of years before present (Ma). The cyan buttons show the layers present at each age. This important display forms the basis of subsequent HOTPOT data processing options.

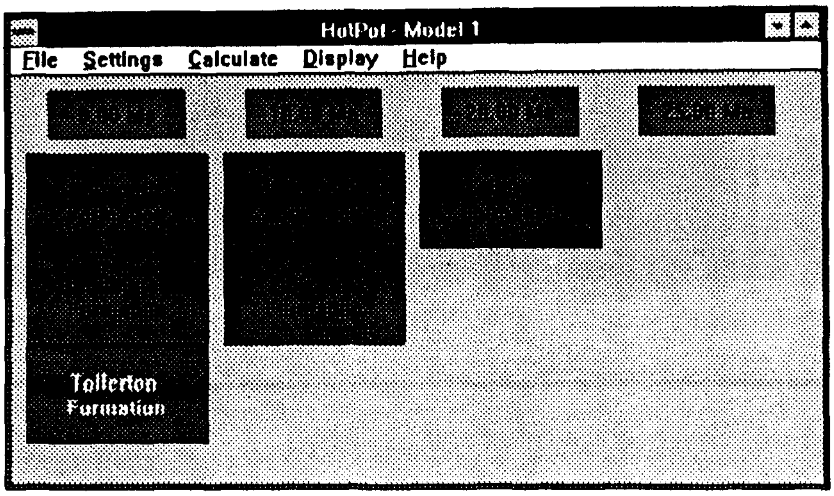


Figure 4.19

4.2.6 Display of the backstripped data

There are two types of display:

a) displays related to an age button

b) displays related to a layer button

The age-related display options

Select **10.00 Ma** button	*The black text of the 10.00 Ma button is changed to white, indicating that it is selected and, hence, options applicable to the 10 Ma time calibration point are activated.*
Choose **Display** menu	*This menu lists all the display options. Only those currently available are enabled (i.e. shown in black text). Display availability is controlled by the data that have been loaded, the calculations that have been performed and the button selected in the main window. Here, the Depth/Density option and the group of three age-related display options are enabled. Each can be displayed by choosing its menu option.*
Choose **Loaded thickness** option	*A Grid Display Window opens, overlapping the main window, Fig. 4.20. A map of total sediment thickness at 10 Ma is shown in this window. This window is now the active window, indicated by its blue caption-bar. You use it independently of the main window (it may be moved, resized, maximized or minimized).*

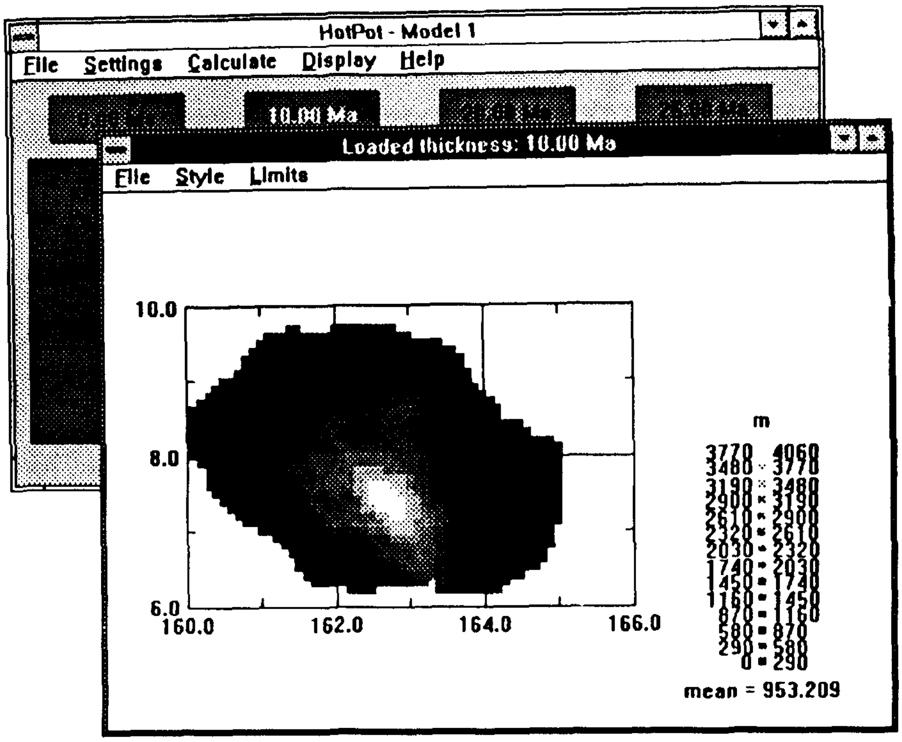


Figure 4.20

If you have a printer available on your computer: Choose the grid display window **File** menu	*This drop-down menu controls data output from the grid display.*
and then choose **Print** option	*The grid-map is printed. The representation of the colours will depend on the printer. Colour printers should show the colours as seen on-screen. Black-and-white printers should produce a grey-scale image. [Some printers may produce a better grey-scale from the HotPot alternative colour palette. To try this: choose* **Style** *menu, then choose* **Alternate colours** *option, then repeat the print operation.]*
Choose grid display window **File** menu, then choose **Close** option	*This closes the grid display window. The HotPot Main Window is redisplayed.*
Choose **Display** menu then choose **Starved thickness** or **Bulk density** option	*The other available age-related options (Starved thickness and Bulk density) can be displayed and printed, as required. Their grid display windows should be used as described for Loaded thickness, above.*
Select **0.00 Ma** or **20.00 Ma** button	*By selecting the other age-buttons (0 or 20 Ma) it is possible to display the other age-related options, as required, in the manner described above for 10 Ma.*

The layer-related display options

Select **Tollerton Fm** button in column under **10.00 Ma** button	*The text on the button changes to white to indicate selection.*

Choose **Display** menu	*Two layer-related options are shown enabled (black text): Layer thickness and Layer density. Either can be chosen for display.*
Choose **Layer thickness**	*A map of (decompacted) Tollerton Fm isopachs at 10 Ma is shown in a Grid Display Window, Fig. 4.21. This window becomes the active window (blue caption bar).*

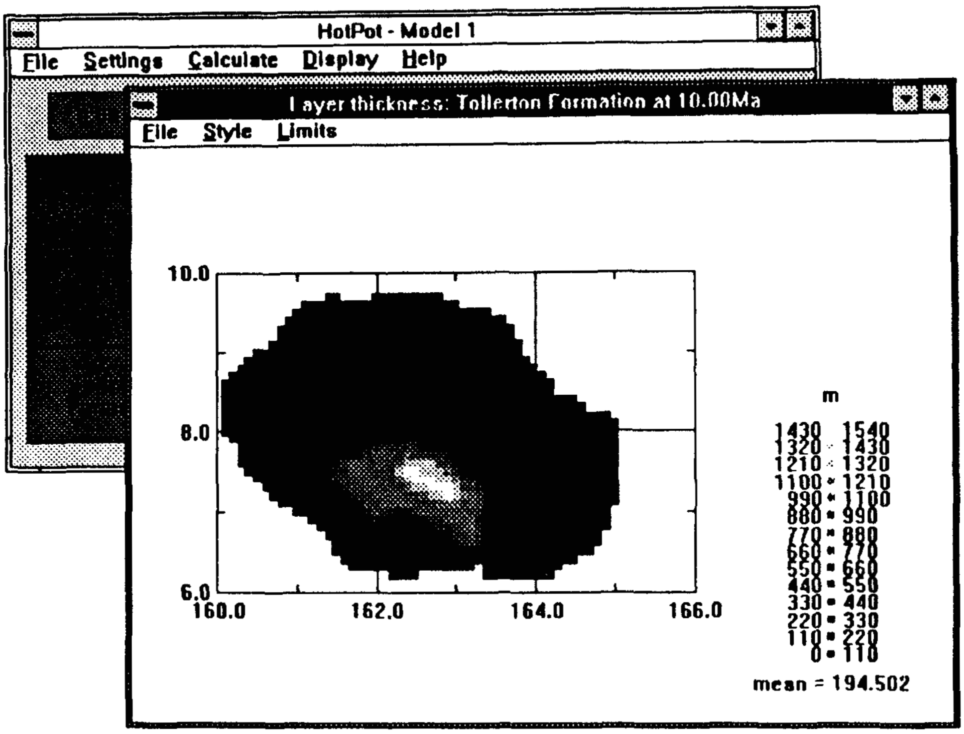


Figure 4.21

If you have a printer available on your computer: Choose grid display window **File** menu and then choose **Print** option	*The grid map is printed.*
Choose grid display window **File** menu, then choose **Close** option	*This closes the grid display window. The HOTPOT Main Window is redisplayed.*
Choose **Display** menu	
Choose **Layer density**	*A map of the (decompacted) density of Tollerton Fm at 10 Ma is displayed, Fig. 4.22. The map may be printed by choosing Print from the File menu, as before. Note that the zero thickness nodes are assigned null in the density grid, i.e. densities are only displayed where the layer is present.*
Choose grid display window **File** menu, then choose **Close** option	*This closes the grid display window. The HOTPOT Main Window is redisplayed.*
	By selecting the other layer buttons it is possible to obtain thickness and density displays of all the individual layers for each of the time-calibration points, as required.

These displays complete the backstripping and decompaction part of the program.

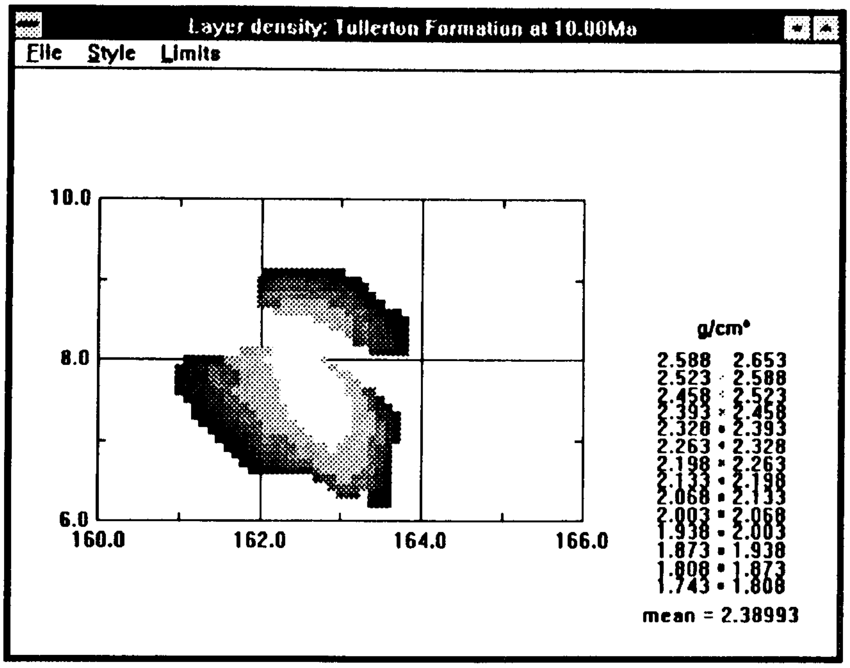


Figure 4.22

Adding annotation to displays

HOTPOT has a facility to draw geographic features, such as coastlines, rivers etc., on the grid maps. This is called *annotation*. The co-ordinate data, e.g. digitised coastline, are stored in *annotation files*. The format of annotation files is described in Appendix II.3. An example annotation file, **coast.dat**, is supplied with the Tutorial data set.

Choose **File** menu from the HOTPOT Main Window menu bar

Choose **Annotation...** option	*A file-list dialogue opens, for you to select one or more annotation files.*
Choose **coast.dat** from **Files** list	*The full file path name, c:\tutorial\coast.dat, is copied into the Selected files list in the top half of the dialogue (Fig. 4.23).*
Choose **Ok** button	*The file-list dialogue closes. The selected annotation file is stored within the program.*
Choose **Display** menu	*Options appropriate to the currently selected age or layer button will be enabled.*
Choose a map display option, e.g. **Layer thickness**	*The chosen data are displayed as a map in a grid display window.*
Choose **Style** menu	*This drop-down menu contains options which control the style of display. Currently selected options are checkmarked.*
Choose **Annotate** option	*The map is redisplayed with a coastline overlay, Fig. 4.24. Note that this slows down the display speed. [This is why the Annotate option is not normally selected.]*

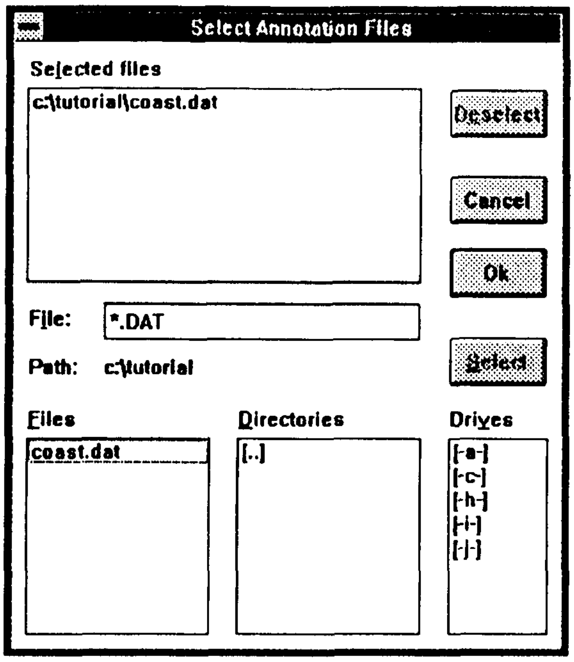


Figure 4.23

Choose **Style** menu — *Note that the* Annotate *option is checkmarked.*

Choose **Annotate** option again — *The map is redisplayed without the coastline overlay.*

- *When annotation is* on, *choosing* Annotate *switches it* off.
- *When annotation is* off, *choosing* Annotate *switches it* on.

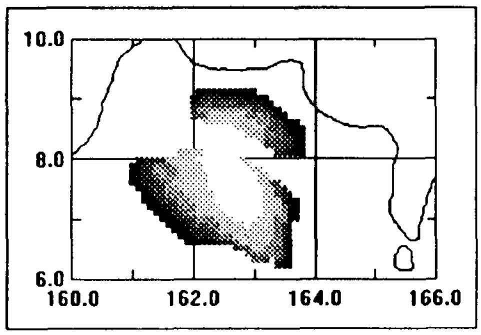


Figure 4.24

This method of annotation is appropriate where geographic features need to be shown on the map in precise position. The reduction in display speed means that it is generally only worthwhile using it for maps which you are printing.

You can also annotate maps by saving the HotPot screen displays into the Windows Clipboard, starting a graphics program (such as Windows Paintbrush) and pasting the display from the Clipboard into the graphics program. All the facilities of the graphics program are then available to edit the picture. Many of the illustrations in this report were prepared using this method. The *Microsoft Windows User's Guide* describes how window displays are saved into the Clipboard and pasted from the Clipboard into Paintbrush. If you use a Windows-based word processor, you can use this technique to insert HotPot displays into report texts.

4.2.7 Load auxiliary depth/thermal-conductivity data

Before carrying out the thermal calculation, a table of thermal-conductivity *vs.* depth data must be loaded from an auxiliary data file.

Choose **File** menu

Choose **Depth/conductivity...** option — *A file selector dialogue opens for you to choose a depth/thermal conductivity file.*

Choose **malay.dkt** from **Files** list

The dialogue closes and the depth/conductivity table is loaded into the program.

4.2.8 Set the layer thermal conductivities

You must now link the depth/conductivity table to each layer, at each time calibration point, in turn.

Select **Keyworth Fm** button under **0.00 Ma** button

The text on the button changes to white to indicate selection.

Choose **Settings** menu

Choose **Conductivity...** option

The Set Thermal Conductivity dialogue opens. This allows you to choose either constant value or depth-variable thermal conductivity for the selected layer.

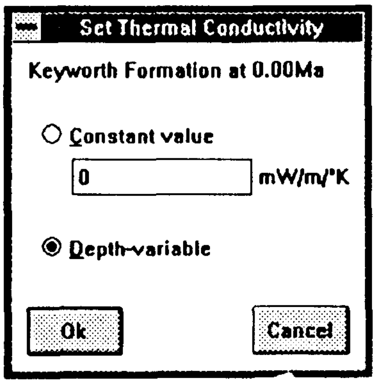


Figure 4.25

Select **Depth-variable** radio button

The depth/conductivity table is linked to the Keyworth Fm at 0 Ma, Fig. 4.25.

Choose **Ok** button

The dialogue closes, completing the setting.

Select **Ruddington Fm** button under **0.00 Ma** button

The procedure is repeated to link the depth/conductivity table to the Ruddington Fm at 0 Ma.

Choose **Settings** menu

Choose **Conductivity...** option

Select **Depth-variable** radio button

Choose **Ok** button

Now repeat the procedure for the remaining 4 layers i.e.

Tollerton Fm at 0.00 Ma
Ruddington Fm at 10.00 Ma
Tollerton Fm at 10.00 Ma
Tollerton Fm at 20.00 Ma

When this has been done, the depth/conductivity table from malay.dkt is linked to all of the basin layers (present-day and decompacted).

4.2.9 Set age-related thermal parameters

You must now specify further thermal parameters to the program. These parameters, surface temperature and heatflow, may change during basin evolution, so they are defined explicitly for each time calibration point.

Select **0.00 Ma** button

The text on the button changes to white to indicate selection. This means that thermal parameters set subsequently will apply to the 0 Ma (present-day) time calibration point.

Choose **Settings** menu

Choose **Surface temperature...** option

The Set Surface Temperature dialogue opens for the selected time-calibration point (0 Ma).

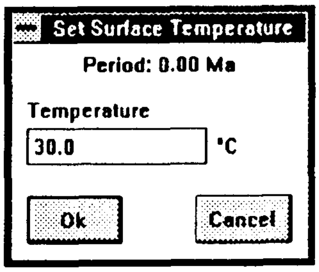


Figure 4.26

Type **30.0** in **Temperature** box, then choose **Ok** button (or press RETURN key)

This sets the surface temperature at 0 Ma to the assumed present day mean annual surface (or seabed) temperature. In this Tutorial the required value is 30°C, Fig. 4.26.

Choose **Settings** menu

Choose **Heatflow...** option

The Set Heatflow dialogue opens for the selected time-calibration point (0 Ma).

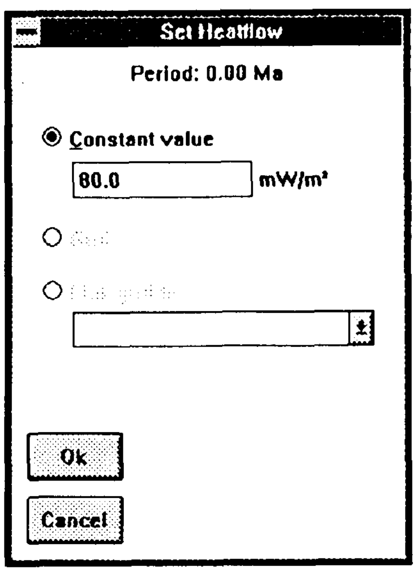


Figure 4.27

Type **80.0** in **Constant value** box, then choose **Ok** button (or press RETURN key)	*This sets the heatflow at 0 Ma to the required value, in this case, to 80 mW m^{-2}. Note that the* **Constant value** *radio button is automatically selected as you enter the value (Fig. 4.27).*
Select **10.00 Ma** button	*This links the following thermal parameters to 10 Ma.*
Choose **Settings** menu	
Choose **Surface temperature...** option	
Type **30.0** in **Temperature** box, then choose **Ok** button (or press RETURN key)	*For this tutorial model, assume that surface temperatures remained constant through time. Though this need not be true in other cases.*
Choose **Settings** menu	
Choose **Heatflow...** option	
Type **80.0** in **Constant value** box, then choose **Ok** button (or press RETURN key)	*For this tutorial model, assume that heatflow remained constant through time. Though this need not be true in other cases.*
Now repeat the procedure for the remaining two time-calibration points, i.e. 20.00 Ma 25.00 Ma	*Set the thermal parameters for 20 Ma and for 25 Ma (the onset of basin development).*

The thermal parameters (conductivity, surface temperature and heatflow) are now fully defined.

4.2.10 Printing a model report

It is advisable at this stage to check that the model parameters are correct by obtaining a summary print-out (if you have a printer available on your computer):

Choose **File** menu

Choose **Print** option	*A report on the model parameters is printed. Compare the data shown in this report to the data values given in the instructions above. If any are incorrect, you must repeat the relevant instructions. The report text is reproduced here as Table 4.3.*

4.2.11 Thermal calculation

HotPot is now ready to carry out the thermal computation.

Choose **Calculate** menu

Choose **Geothermal** option	*A progress dialogue shows information about the thermal modelling process. This shows the name and age of each layer processed, the type of calculation being performed and the percentage completed.*

Table 4.3

```
HotPot - Model 1

Depth/Density file: c:\tutorial\malay.ddt

Depth/Thermal-conductivity file: c:\tutorial\malay.dkt

Area of Interest...
        [file: c:\tutorial\tutorial.aoi]

        Western limit = 160
        Eastern limit = 166
        East/West spacing = 0.1
        No. East/West nodes = 61

        Southern limit = 6
        Northern limit = 10
        North/South spacing = 0.1
        No. North/South nodes = 41

Age of top of top layer = 0.00Ma

Initial stratigraphy...

        Formation: Keyworth Formation
        Age 10.00Ma at base
        Lithology: SST
        Water depth 0.0m at end of deposition
        Isopach files:
                c:\tutorial\keyworth.iso

        Formation: Ruddington Formation
        Age 20.00Ma at base
        Lithology: SST = 50%  LST = 50%
        Water depth 10.0m at end of deposition
        Isopach files:
                c:\tutorial\ruddinga.iso

        Formation: Tollerton Formation
        Age 25.00Ma at base
        Lithology: MDSLST
        Water depth 30.0m at end of deposition
        Isopach files:
                c:\tutorial\toller.iso

Basin history...

        Period: 0.00Ma
        Surface temperature 30.0°C
        Constant heatflow 80mW/m²

                Formation: Keyworth Formation
                Thermal conductivities calculated from depths

                Formation: Ruddington Formation
                Thermal conductivities calculated from depths

                Formation: Tollerton Formation
                Thermal conductivities calculated from depths

        Period: 10.00Ma
        Surface temperature 30.0°C
        Constant heatflow 80mW/m²

                Formation: Ruddington Formation
                Thermal conductivities calculated from depths

                Formation: Tollerton Formation
                Thermal conductivities calculated from depths

        Period: 20.00Ma
        Surface temperature 30.0°C
        Constant heatflow 80mW/m²

                Formation: Tollerton Formation
                Thermal conductivities calculated from depths

        Period: 25.00Ma
        Surface temperature 30.0°C
        Constant heatflow 80mW/m²
```

4.2.12 Display of thermal model results

Display control is similar to that described for the backstripped sequence (4.2.6). The thermal results are all layer-related. To enable the layer-related options, select the desired layer button, for example:

Select **Tollerton Fm** button under **10.00 Ma** button — *The text label of the button changes to white to indicate selection.*

Choose **Display** menu — *In addition to the earlier options (4.2.6),* **Layer conductivity** *and* **Layer temperature** *are now enabled (black text); either can be displayed by choosing it.*

Choose **Layer temperature** option — *A map of the temperature of the base of the Tollerton Fm at 10 Ma is shown in a grid display window, Fig. 4.28. Note that nodes in the temperature grid are set null where corresponding nodes in the thickness grid are zero, i.e. temperatures are only displayed where the layer is present. (Compare figures 4.21 and 4.28.)*

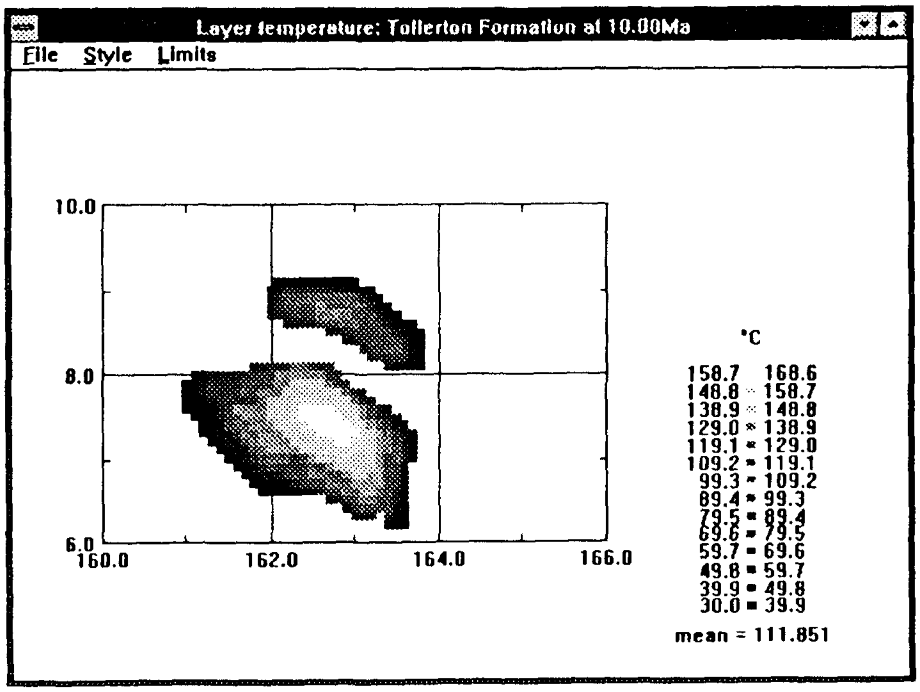


Figure 4.28

If you have a printer available on your computer: Choose **File** menu from the grid display window, then choose **Print** option — *The temperature map is printed.*

In addition to the °C temperature scale it is possible to display the temperature grid on a thermal maturity scale

Choose **Limits** menu — *This drop-down menu allows you to specify the limits of the colour scale used to draw the map.*

Choose **Pseudo-maturity** option

A map of the level of organic maturity is displayed in the window, Fig. 4.29. The map can be printed by choosing ***File*** *then* ***Print****.*

Note that this pseudo-maturity scale is based solely on the temperature of the selected layer. It is not a TTI-type maturity scale.

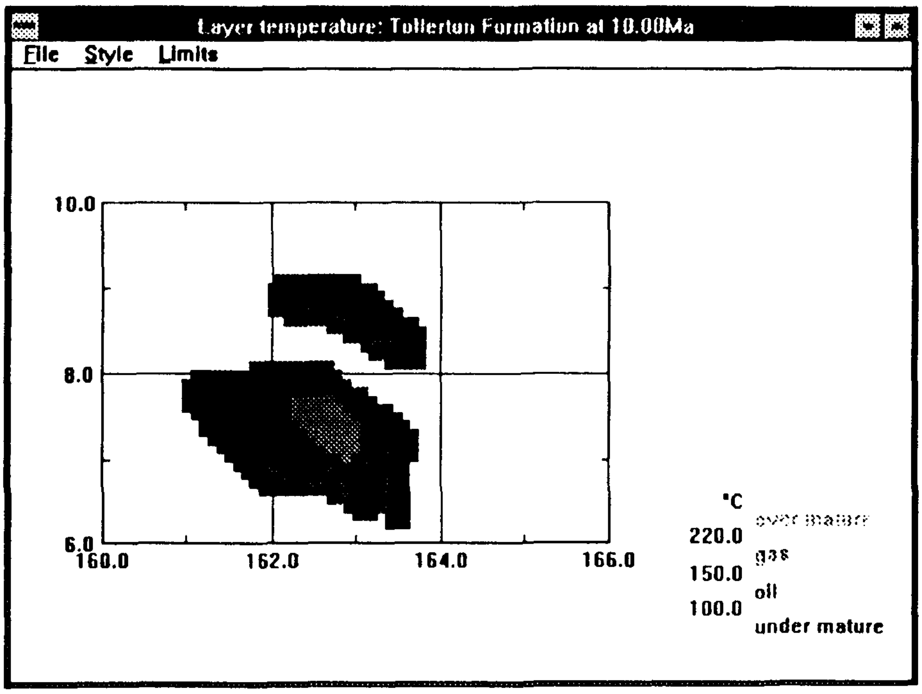


Figure 4.29

Choose grid display window **File** menu, then choose **Close** option

The grid display window closes and the HOTPOT Main Window is redisplayed.

Choose **Display** menu

Choose **Layer conductivity** option

A map of the computed thermal conductivity of (decompacted) Tollerton Fm at 10 Ma is shown in a grid display window, Fig. 4.30. The map can be printed by choosing ***File*** *then* ***Print****.*

Choose grid display window **File** menu, then choose **Close** option

By selecting the other layer buttons it is possible to obtain temperature, maturity and thermal conductivity displays of all the layers available at any age, as required.

These display options comprise the basic grid-map output of a complete HOTPOT modelling session.

4.2.13 Additional display options

In addition to the grid-map displays, other display options are available within HOTPOT. The most important of these involve the extraction of information about individual grid nodes, giving local 1-D burial and thermal history plots.

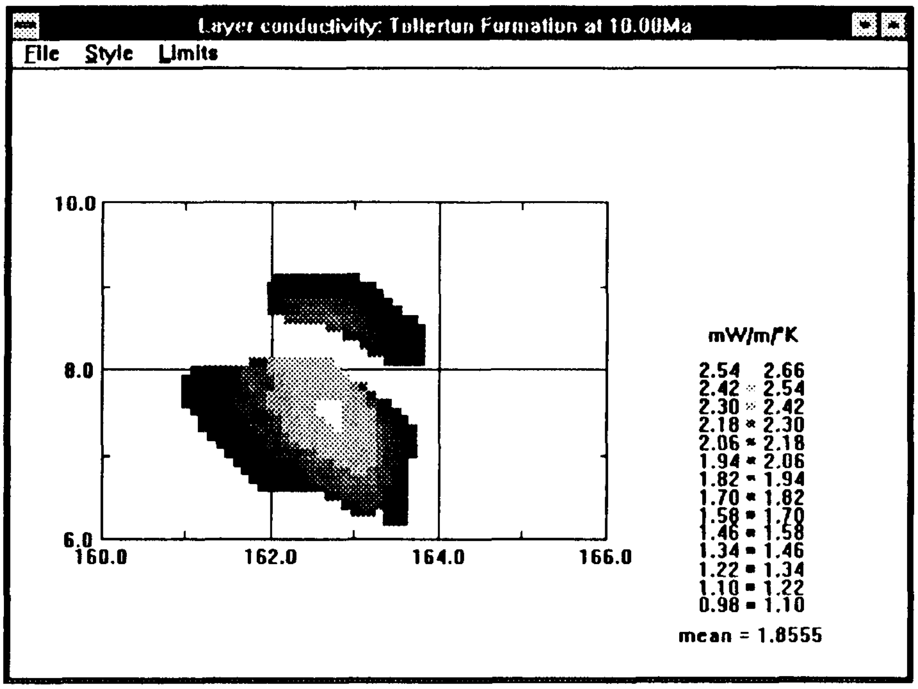


Figure 4.30

Age-related display options

Select **0.00 Ma** button

Choose **Display** menu

Choose **Loaded thickness** option — *A map of the total sediment thickness at 0 Ma (present day) is displayed in a grid display window.*

Move the cursor to any node on the grid and click the left mouse button to select the node — *The X,Y co-ordinates and thickness value (Z) of that grid node are displayed at the right of the window menu-bar, Fig. 4.31.*

Figure 4.31

Double-click the left mouse button while keeping the cursor on the selected grid node. — *The burial history curve (total sediment thickness against time) of the grid node is drawn in a graph display window, Fig. 4.32. (This window now becomes the active window.) This corresponds to the burial history of the base of the bottom layer (Tollerton Fm) at the grid node. The graph may be printed by choosing File then Print.*

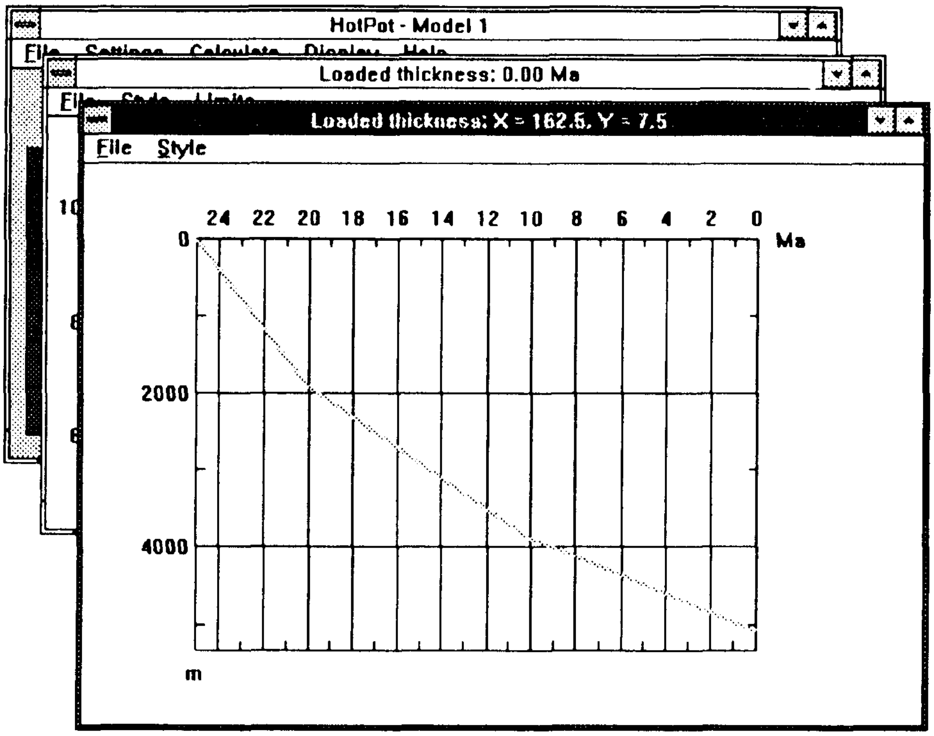


Figure 4.32

Choose graph display window **File** menu, then choose **Close** option — *The graph display window closes and the grid-map is redisplayed. It is then possible to display the burial histories of other grid nodes, as required, in the same manner.*

Choose grid display window **File** menu, then choose **Close** option — *The grid display window closes and the HOTPOT Main Window is redisplayed.*

Layer-related display options

Select **Keyworth Fm** button under **0.00 Ma** button

Choose **Display** menu

Choose **Layer thickness** option — *A map of the thickness of Keyworth Fm at 0 Ma (present day) is drawn in a grid display window.*

Move the cursor to any node on the grid and select the node by clicking the left mouse button. — *The X,Y co-ordinates and the thickness (Z) value are given at the right of the menu-bar.*

Double-click the left mouse button while keeping the cursor on the selected grid node. — *The burial history of all three layers at the grid node is drawn in a graph display window, Fig. 4.33. The graph may be printed by choosing File then Print options.*

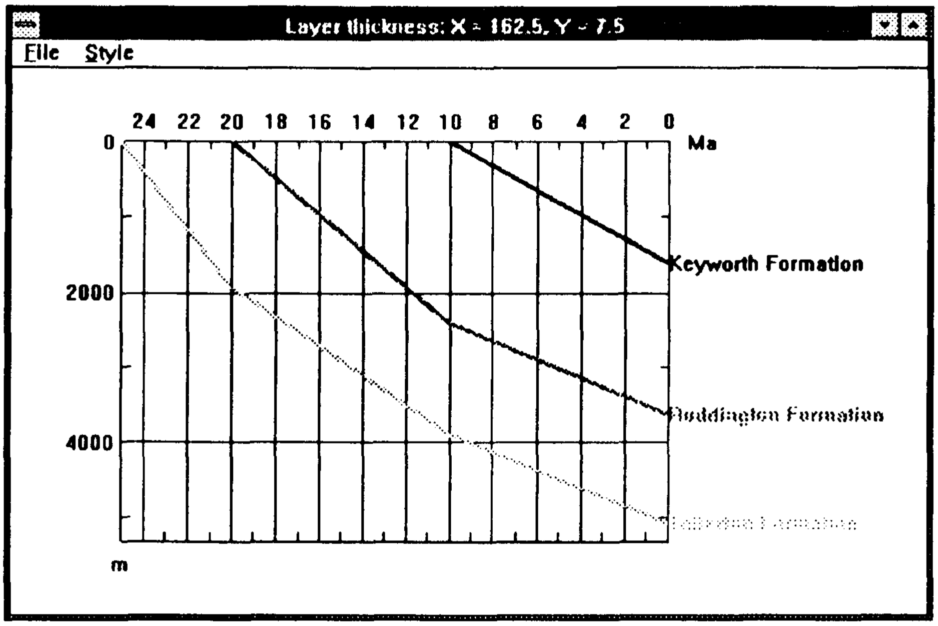


Figure 4.33

Choose graph display window **File** menu, then choose **Close** option

The layer thickness map is redisplayed, allowing other grid nodes to be selected and displayed in the same manner.

Choose grid display window **File** menu, then choose **Close** option

The HOTPOT Main Window is redisplayed.

Choose **Display** menu

Choose **Layer temperature** option

A map of the temperature of the base of the Keyworth Fm at 0 Ma (present day) is displayed in a grid display window.

Move the cursor to any node on the grid and select the node by clicking the left mouse button.

The X,Y co-ordinates and the temperature (Z) value are given at the right of the menu-bar.

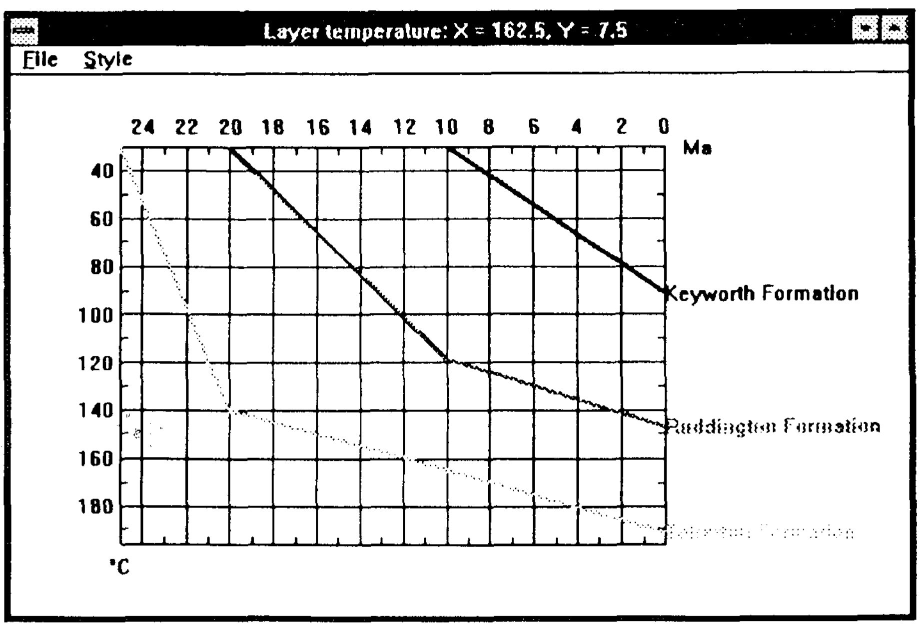


Figure 4.34

Double-click the left mouse button while keeping the cursor on the selected grid node.

The thermal history of all three layers at the grid node is drawn in a graph display window, Fig. 4.34. The graph may be printed by choosing File then Print options.

Choose graph display window **File** menu, then choose **Close** option

The temperature grid-map is redisplayed, allowing other grid nodes to be selected and displayed in the same manner.

Choose grid display window **File** menu, then choose **Close** option

The HOTPOT Main Window is redisplayed.

You may display grid node extractions of other results (sediment-starved thicknesses, layer densities, layer conductivities etc.) in the same way, as required.

Auxiliary data displays

You may also display the contents of the auxiliary data files:

Choose **Display** menu

Choose **Depth/density** option

The depth/density relationship stored in the auxiliary data file malay.ddt is drawn in a graph display window, Fig. 4.35. It may be printed by choosing File then Print.

Choose graph display window **File** menu, then choose **Close** option

The HOTPOT Main Window is redisplayed.

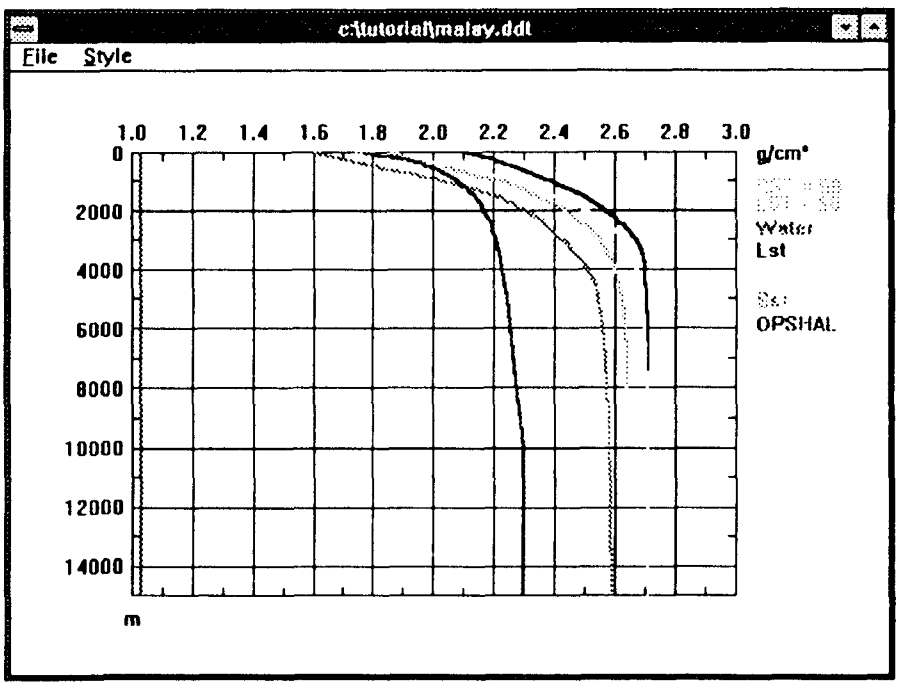


Figure 4.35

Choose **Display** menu

Choose **Depth/conductivity** option	*The depth/thermal conductivity relationship stored in the auxiliary data file* malay.dkt *is drawn in a graph display window, Fig. 4.36. It may be printed by choosing* **File** *then* **Print** .
Choose graph display window **File** menu, then choose **Close** option	*The HotPot Main Window is redisplayed.*

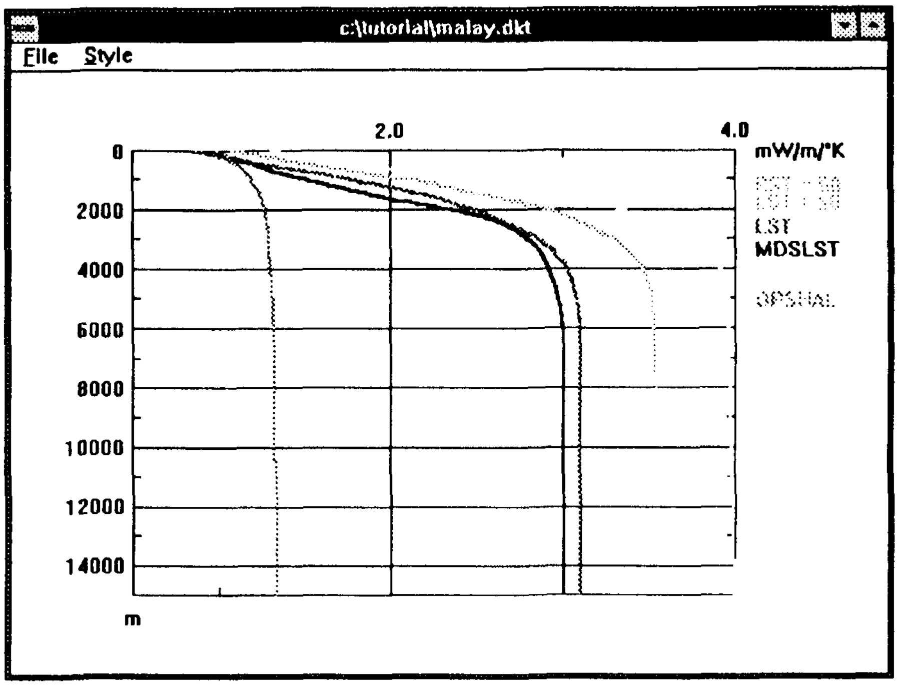


Figure 4.36

4.2.14 End modelling session

Choose **File** menu	
Choose **Exit** option	*This closes the HotPot program. Because a model is loaded into the program, HotPot will open a dialogue, Fig. 4.37, asking you to confirm your intention to delete the model and exit.*

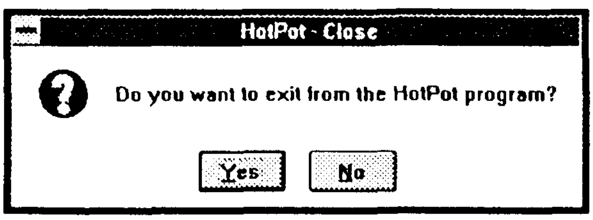


Figure 4.37

Choose **Yes** button	*The model is deleted. The HotPot program closes and the Windows desktop is redisplayed.*
Take a coffee break	*You've earned it!*

4.3 Tutorial Model 2

This model shows the use of time and spatially variant heatflow. The modelling session illustrates:

- how some of the modelling procedures can be reorganised to improve efficiency
- how the area of interest specification is entered and saved for use in later modelling sessions
- how the layer information is entered and saved for use in later modelling sessions
- how gridding search radii are chosen
- how the density of digitised data affects gridding and the need to include *control contours* and *anti-masking contours* in the data sets prepared for use with HOTPOT
- how model data grids can be saved for use in later modelling sessions

(Note that we refer to some of the instructions given for Model 1 rather than repeat them here.)

4.3.1 Set the model title

Carry out the instructions given in Section 4.2.1, but set the title to **Model 2** instead of Model 1	*The title is shown on the main window caption bar.*

4.3.2 Define the area of interest

In Model 1 you used an area of interest definition which we had prepared and saved in a file. Here, you will enter the definition yourself and save it for use in Model 3. Saving an area of interest definition enables you to re-run modelling sessions quickly and easily.

The geographical limits of the area of interest for the Tutorial data set are specified in latitude and longitude degrees. When you use your own data, you may use other units; geographical co-ordinate systems are discussed in Appendix II.2.3.

Choose **Settings** menu

Choose **Area of interest...** option	*The area of interest dialogue opens. The insertion point (flashing cursor) is in the* North *box*
Type **10.0** into **North** box	*Sets the northern limit of the area to be latitude 10°N*
Press TAB key	*Insertion point moves to* South *box*
Type **6.0** into **South** box	*Sets the southern limit of the area to be latitude 6°N*
Press TAB key	*Insertion point moves to* N-S spacing *box*
Type **0.1** into **N-S spacing** box	*Sets the spacing between grid nodes in the north-south direction (i.e. the distance between adjacent grid rows) to be 0.1°*

Press TAB key	*Insertion point moves to* West *box*
Type **160.0** into **West** box and press TAB key	*Sets the western limit of the area of interest to be longitude 160° E. Insertion point moves to* East *box.*
Type **166.0** into **East** box and press TAB key	*Sets the eastern limit of the area of interest to be longitude 166° E. Insertion point moves to* W-E spacing *box.*
Type **0.1** into **W-E spacing** box	*Sets the spacing between grid nodes in the west-east direction (i.e. the distance between adjacent grid columns) to be 0.1°*
Choose **Apply** button	*The values entered in the boxes are verified. The* N-S nodes *and* W-E nodes *boxes are updated with the numbers of grid nodes in the north-south and west-east directions, respectively, Fig. 4.38. These numbers are calculated from the grid dimensions and spacings you entered.*

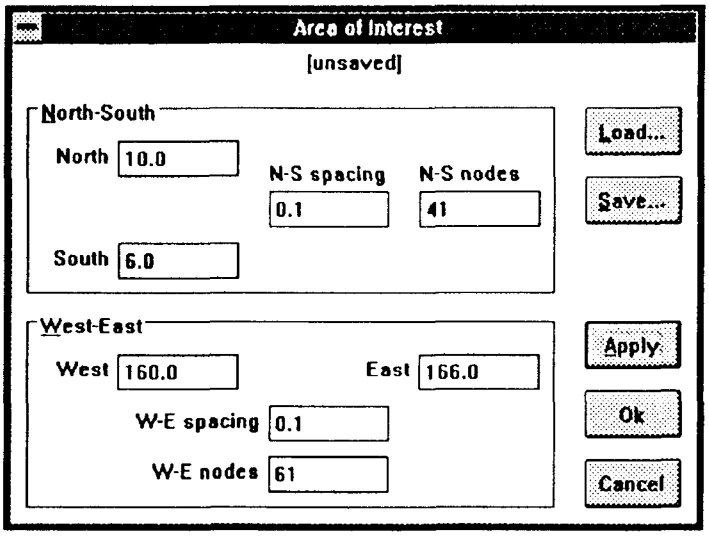


Figure 4.38

Choose **Save...** button	*Opens a file selector dialogue for you to save the area of interest definition*
Use **Directories** list box to find the **c:\tutorial** directory	
Type **model** into **File** box, then choose **Ok** button (or press RETURN key)	*Figure 4.39. The file selector closes and the AoI definition is saved into the file* c:\tutorial\model.aoi *(note that the* .aoi *file type is automatically added by the file selector).*
	The area of interest dialogue remains open. The file name is now shown under the caption bar of the dialogue.
Choose **Ok** button	*The area of interest dialogue closes and the definition is complete.*

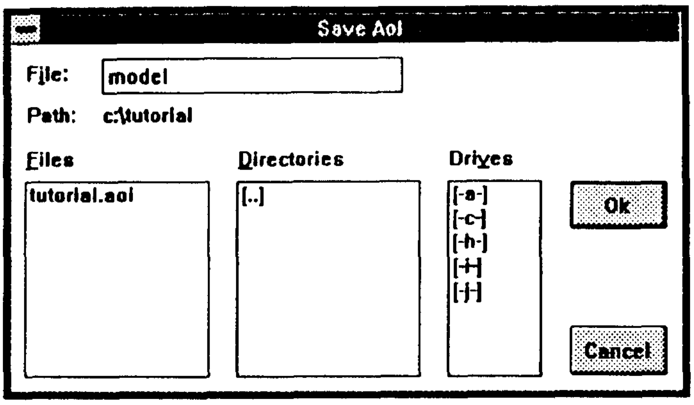


Figure 4.39

4.3.3 Load auxiliary depth/density data

HOTPOT requires both depth/density data and layer data in order to do the decompaction calculation. However, the order in which they are loaded is not important.

Carry out the instructions given in
Section 4.2.4

4.3.4 Load auxiliary depth/thermal conductivity data

Loading the depth/thermal conductivity data now will allow you to set the layer thermal conductivities *before* doing the decompaction calculation. The settings will then be copied to the layers at 10 Ma and 20 Ma by the backstripping process, which will save you setting them manually later.

Carry out the instructions given in
Section 4.2.7

4.3.5 Load the layer data

In this modelling session, you will save all the grids that you calculate for use in Model 3. Saving grids enables you to re-run modelling sessions quickly and easily.

As each layer is loaded, you will set its thermal conductivity parameter; this is an efficient working practice.

Keyworth Formation

In Model 1 you used layer information which we had prepared and saved in files. Here, you will enter the layer information for the Keyworth Formation yourself and save it for use in Model 3. Saving layer information enables you to re-run modelling sessions quickly and easily.

Choose **File** menu

Choose **Layer...** option	*The layer information dialogue opens. The insertion point (flashing cursor) is in the* Formation name *box.*

Type **Keyworth Formation** in **Formation name** box

This sets the name used to identify the formation. Formation names may contain any printable characters and include spaces.

Press TAB key

Insertion point moves to the **Lithology code** *box.*

Type **SST** in **Lithology code** box, then press TAB key

This sets the lithology to be pure (i.e. 100%) sandstone.

The TAB moves the insertion point to the **Age at base** *box.*

Type **10** in **Age at base box,** then press TAB key

This sets the age of the base of the layer to be 10 Ma.

The TAB moves the insertion point to the **Water depth** *box.*

Type **0** in **Water depth** box

The water depth was 0 metres when deposition of the layer finished.

Select **m** radio button in **Isopach Units** group box.

The isopach data are in metres.

The dialogue should now look like Figure 4.40.

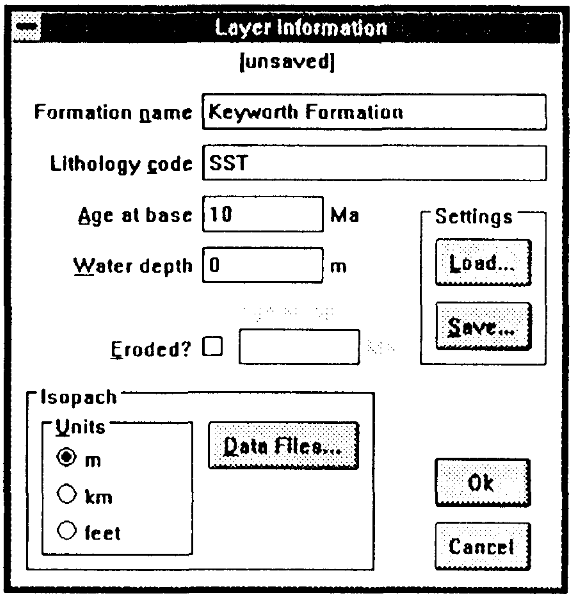


Figure 4.40

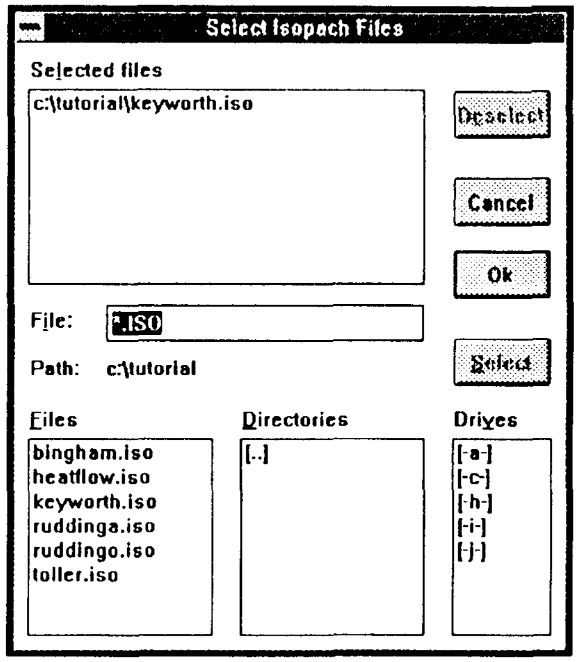


Figure 4.41

Choose **Data files...** button in **Isopach** box

This opens a file-list dialogue for you to select one or more digitised isopach data files to be used for subsequent gridding.

Choose **keyworth.iso** from **Files** list

The full file path name c:\tutorial\keyworth.iso *is copied into the* Selected files *list box, in the upper part of the dialogue, Fig. 4.41..*

[In this model you are only using one file; however, this dialogue allows multiple file selection, unlike the normal file selector dialogue which only allows single file selection.]

Choose **Ok** button

This closes the file-list dialogue and returns to the layer information dialogue.

Choose **Save...** button

A file selector dialogue opens.

Type **kw** in **File** box, then choose **Ok** button (or press RETURN key)

The file selector closes. The contents of the layer information dialogue (including the name of the isopach data file, keyworth.iso*) are saved in the file* kw.lay *for use in a later modelling session. Note that the file selector will automatically add the* .lay *file type for you.*

The layer information dialogue remains open. The file name is now shown under the caption bar of the dialogue.

Choose **Ok** button

The gridding window opens.

Choose **Grid...** button

The search radius dialogue opens.

Type **0.16** into **Radius** box, then choose **Ok** button (or press RETURN key)

The program grids the isopach data with a search radius of 0.16° and displays a grid map (as Fig. 4.12, Model 1).

This prepares an acceptable grid, which you will save for later use, in Model 3.

Choose the gridding window **File** menu

This drop-down menu is used to control input and output of gridded data.

Choose **Save...** option

This is used to save a grid for use in a later modelling session, to avoid repeating the gridding calculation. A file selector dialogue opens, Fig. 4.42.

Type **keyworth** into **File** box

The file selector will offer an automatically generated, unique file name, Fig. 4.42a. You replace this with a more meaningful name, Fig. 4.42b.

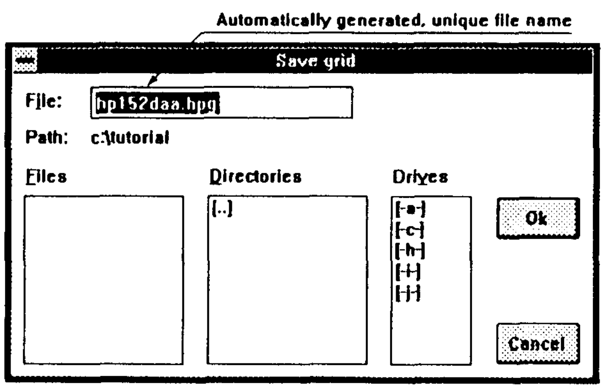


Figure 4.42a

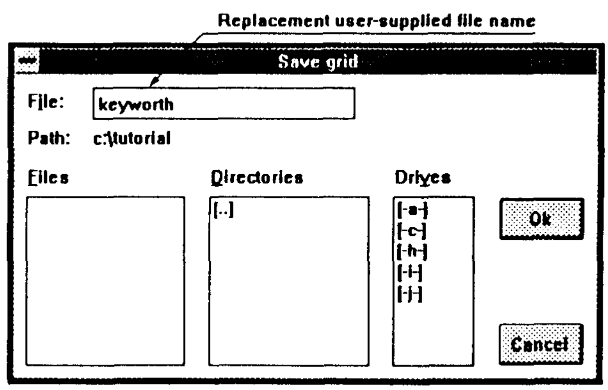


Figure 4.42b

Choose **Ok** button (or press RETURN key)

The file selector closes and HOTPOT saves the grid data into the file keyworth.hpg *[note that the file selector will add the* .hpg *for you].*

Choose **Accept** button

The grid is accepted and the gridding window closes. The HOTPOT Main Window shows a Keyworth Fm layer button. Note that the Keyworth Fm button has its name in white text, to indicate that it is selected.

Choose **Settings** menu	
Choose **Conductivity...** option	*Opens the Set Thermal Conductivity dialogue for the Keyworth Fm.*
Select **Depth-variable** radio button	*Links the depth/thermal conductivity table to the Keyworth Fm at 0 Ma (present day).*
Choose **Ok** button	*Closes the dialogue and completes the setting.*

The Keyworth Formation now has all its data loaded into the model and has its thermal conductivity parameter set.

Ruddington Formation

In loading the data for this layer, you will use two files of layer information which we prepared for you. The first demonstrates a common problem that you may encounter using your own data sets with HotPot. The second shows a method for solving this problem.

Choose **File** menu	
Choose **Layer...** option	*The layer information dialogue opens.*
Choose **Load...** button	*A file selector dialogue opens.*
Choose **ruddingo.lay** from **Files** list	*Layer information is loaded from* ruddingo.lay. *The layer information dialogue is redisplayed with the information shown. This includes a reference to the original digitised isopach file* ruddingo.iso.
Choose **Ok** button	*The gridding window opens.*
Choose **Grid...** button	
Type **0.19** into **Radius** box, then choose **Ok** button (or press RETURN key)	*The program grids the isopach data with a search radius of 0.19° and displays a grid map (Fig. 4.43). There are large areas of null nodes, particularly in the central and eastern parts of the basin. This is because the contours in the original dataset were locally too widely spaced (Fig 4.2a). To grid the dataset without generating null nodes requires a search radius so large that unacceptable smoothing of the map occurs. [You may wish to try some other search radii to confirm this.] The grid must be discarded and additional* control contours *digitised before regridding.*
Choose **Cancel** button	*The grid is discarded, the gridding window closed and the HotPot Main Window redisplayed.*

A revised Ruddington Formation dataset, in which additional *control contours* augment the original dataset (Fig. 4.2b), is stored in the file ruddinga.iso.

Choose **File** menu

Choose **Layer...** option

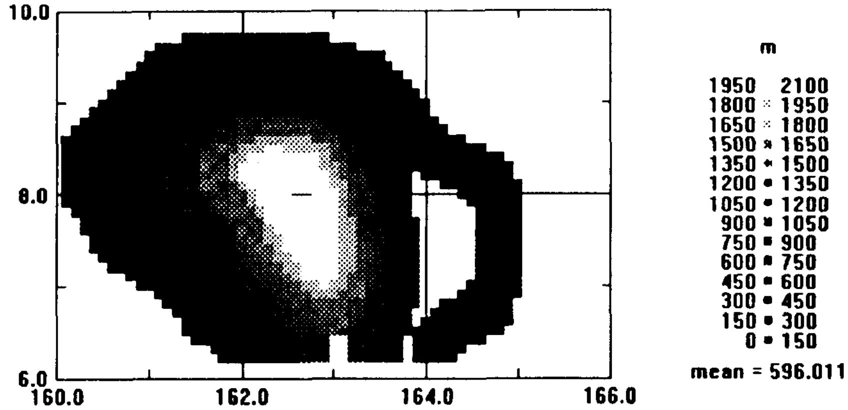


Figure 4.43

Choose **Load...** button

Choose **ruddinga.lay** from **Files** list — *Layer information is loaded from the file* ***ruddinga.lay****. The layer information dialogue is redisplayed with the information shown. This includes a reference to the revised digitised isopach file* ***ruddinga.iso****.*

Choose **Ok** button — *The gridding window opens.*

Choose **Grid...** button

Type **0.19** into **Radius** box, then choose **Ok** button (or press RETURN key) — *The program grids the revised isopach data with a search radius of 0.19° and displays a grid map (Fig. 4.44). The search radius is acceptably small and experimentation shows this to be the smallest radius which yields no null grid-nodes [you may wish to experiment with other search radii]. As well as additional control contours within the zero isopach contour,* ***ruddinga.iso*** *contains zero-value* anti-masking contours *(see 4.1.1) around the margins of the sedimentary-fill. This is seen as a greater area of zero nodes (replacing null nodes) compared to Fig. 4.43.*

This prepares an acceptable grid, which you will save for later use in Model 3.

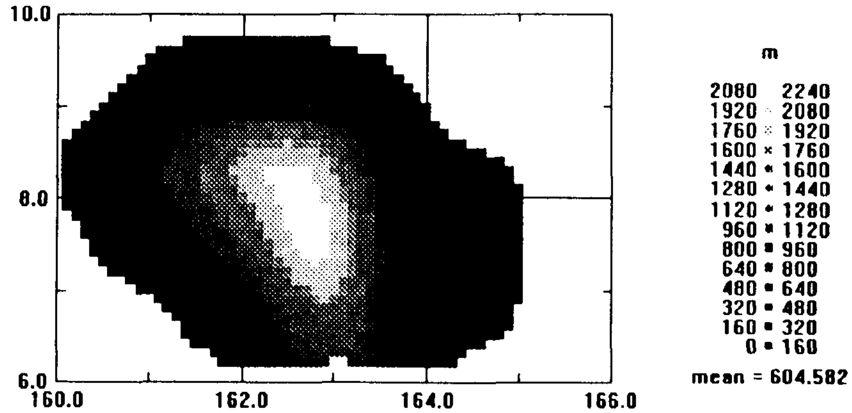


Figure 4.44

Choose the gridding window **File** menu	
Choose **Save...** option	
Type **ruddinga** into **File** box	*The file selector offers an automatically generated, unique file name. You replace this with a more meaningful name.*
then choose **Ok** button (or press RETURN key)	*The file selector closes and HOTPOT saves the grid data into the file ruddinga.hpg*
Choose **Accept** button	*The grid is accepted and the gridding window closes. The HOTPOT Main Window shows a Ruddington Fm layer button below the Keyworth Fm button. The Ruddington Fm button has its name in white text, to indicate that it is selected.*
Choose **Settings** menu	
Choose **Conductivity...** option	*Opens the Set Thermal Conductivity dialogue for the Ruddington Fm.*
Select **Depth variable** radio button	*Links the depth/thermal conductivity table to the Ruddington Fm at 0 Ma (present day).*
Choose **Ok** button	*Closes the dialogue and completes the setting.*

Tollerton Formation

In loading the data for this layer, you may *either* enter the layer information yourself *or* use a file of layer information which we prepared for you. Here, you will experiment with the effects of differing search radii on the grids produced from the data set.

Choose **File** menu	
Choose **Layer...** option	*The layer information dialogue opens.*
To enter layer information yourself: • fill-in the dialogue boxes from the data given in Table 4.1 • specify **toller.iso** as the isopach data file	*In a similar manner to that described for the Keyworth Fm.*
To use saved layer information: • choose **Load...** button • choose **toller.lay** from **Files** list	*Layer information is loaded from file toller.lay, including a reference to the digitised isopach file toller.iso.*
Choose **Ok** button	*The gridding window opens.*
Choose **Grid...** button	

Type **0.1** into the **Radius** box, then choose **Ok** button (or press RETURN key)

The program grids the isopach data with a search radius of 0.1° and displays a grid map (Fig. 4.45). The search radius is too small and null nodes (white) are seen between the bands of colour which follow the contours. The search radius needs to be increased.

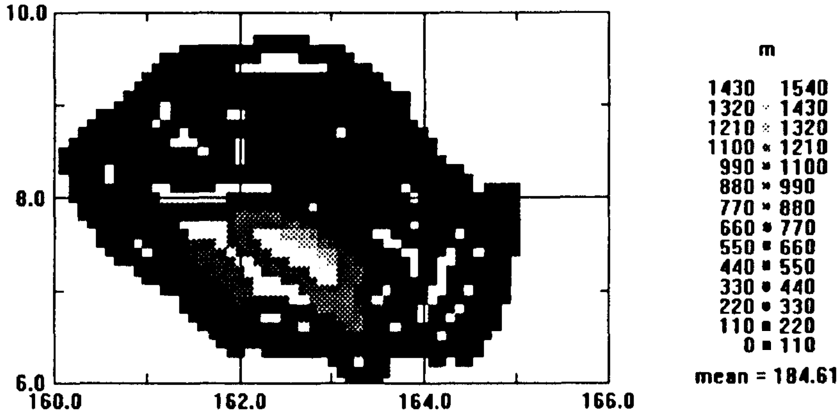


Figure 4.45

Choose **Grid...** button

Type **0.5** into the **Radius** box, then choose **Ok** button (or press RETURN key)

The program grids the isopach data with a search radius of 0.5° and redisplays the grid map (Fig. 4.46). There are now no null nodes (white) between the bands of colour which follow the contours. However, the two small basins, within which the Tollerton Fm exists, now appear to merge (north-east of map centre). The search radius needs to be decreased.

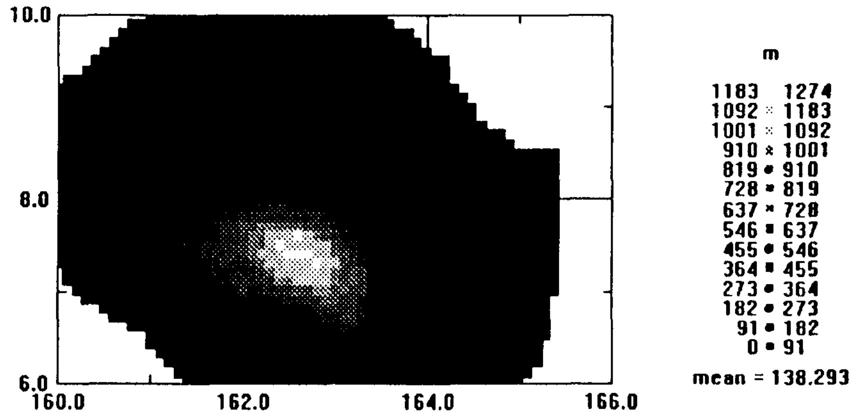


Figure 4.46

Choose **Grid...** button

Type **0.19** into the **Radius** box, then choose **Ok** button (or press RETURN key)

The program grids the isopach data with a search radius of 0.19° and redisplays the grid map (Fig. 4.47). The search radius is now acceptably small. There are no null nodes and separate features are distinct. Note the large area of zero thickness nodes around the actual sedimentary-fill, this is due to zero-value anti-masking contours *(see 4.1.1).*

You will find more information about choosing gridding search radii in Appendix III.

This has prepared an acceptable grid, which you will save for later use in Model 3. You should also, now, appreciate the convenience of being able to save grids for later use.

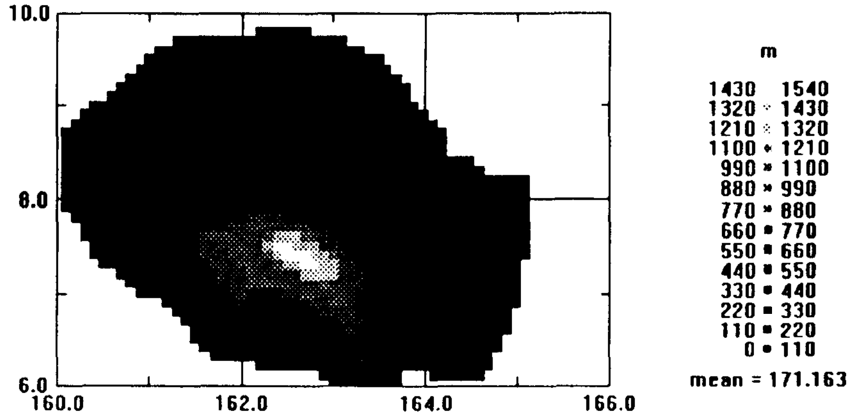


Figure 4.47

Choose the gridding window **File** menu

Choose **Save...** option

Type **toller** into the **File** box, then choose **Ok** button (or press RETURN key)

The file selector closes and HotPot saves the grid data into the file toller.hpg

Choose **Accept** button

The grid is accepted and the gridding window closes. The HotPot Main Window shows the Tollerton Fm layer button below the Ruddington Fm button; it is selected.

Choose **Settings** menu

Choose **Conductivity...** option

Select **Depth variable** radio button

Links the depth/thermal conductivity table to the Tollerton Fm at 0 Ma (present day).

Choose **Ok** button

4.3.6 Decompaction by backstripping

Now all three layers of the model have been loaded and have their thermal properties defined. The auxiliary data tables have been loaded. You are ready to compute the basin history.

Carry out the instructions given in section 4.2.5 for decompacting the model.

The thermal conductivity settings will be copied from the layers loaded to the layers created during backstripping.

4.3.7 Confirm that settings have been copied

Select **Tollerton Formation** button under **20 Ma** button

Choose **Settings** menu

Choose **Conductivity...** option

The Set Thermal Conductivity dialogue is opened for the Tollerton Fm at 20 Ma. Note that the Depth variable *radio button is already selected.*

Choose **Cancel** button (or press ESC key)

Close the dialogue without making any changes.

4.3.8 Display of the backstripped data

Carry out the instructions given in section 4.2.5 for display of the backstripped data.

These displays should be the same as the ones for Model 1 as parameters affecting the decompaction calculation have not been changed.

4.3.9 Setting the age-related thermal parameters for 0 Ma

Now you need to set further thermal parameters in the program. These parameters change during basin evolution, so they are defined explicitly for each time calibration point.

Firstly the heatflow data will be input to HOTPOT. In this Tutorial a heatflow map is available for the present-day (Fig. 4.4), this needs to be *anchored* to the 0.00 Ma time-calibration point.

Select **0.00 Ma** button

Choose **File** menu

Choose **Heatflow...** option

This displays a file-list dialogue, which allows you to select one or more files of digitised heatflow contour data for subsequent gridding.

Choose **heatflow.iso** from the **Files** list

The full file path name c:\tutorial\heatflow.iso *is copied into the* Selected files *list box, in the upper part of the dialogue.*

In this model you are only using one file; however, this dialogue allows multiple file selection, unlike the normal file selector dialogue which only allows single file selection.

Choose **Ok** button	*This closes the file-list dialogue and opens the gridding window, ready for you to grid the heatflow contour data.*
Choose **Grid...** button	*Opens the search radius dialogue.*
Type **0.26** into **Radius** box, then choose **Ok** button (or press RETURN key)	*The program grids the heatflow data with a 0.26° search radius, Fig. 4.48. Experiment shows that this is the smallest value which generates no null nodes, moreover the radius is acceptably small for the smoothly-variable heatflow data.* *[You may, of course, save this grid for future use, in the same way that you saved the layer isopach grids.]*

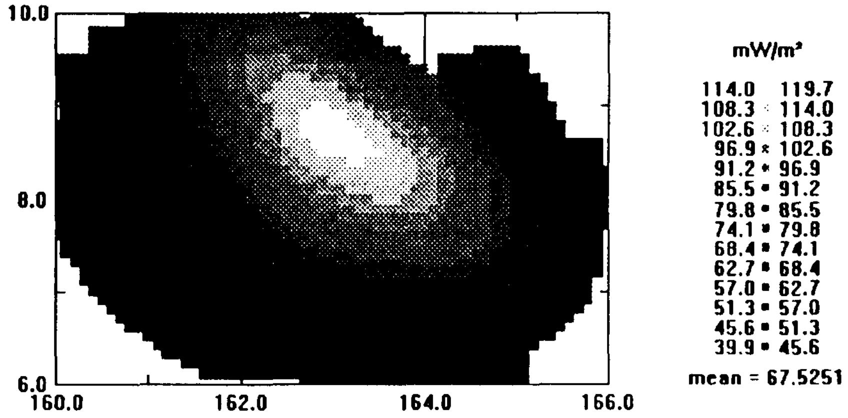


Figure 4.48

Choose **Accept** button	*The HotPot Main Window is redisplayed. The gridded heatflow map is anchored to the 0.00 Ma time-calibration point. This can be tested as follows:*
Choose **Settings** menu	
Choose **Heatflow...** option	*The Set Heatflow dialogue opens for* **0.00 Ma** *with the* **Grid** *radio button already selected, indicating that the heatflow grid is linked to 0.00 Ma and ready for use.*
Choose **Cancel** button	*The Set Heatflow dialogue closes with no changes.* *The 0.00 Ma Button is still selected, enabling the surface temperature to be set.*
Choose **Settings** menu	
Choose **Surface temperature...** option	
Type **30.0** into the **Temperature** box, then choose **Ok** button (or press RETURN key)	*The present-day surface temperature is set to 30°C.*

4.3.10 Setting the remaining age-related thermal parameters

It is most unlikely that the present-day heatflow distribution will be applicable to earlier periods of basin evolution. The earlier time-calibration points will therefore be assigned single-value heatflows as in Tutorial Model 1.

Select **10.00 Ma** button

Choose **Settings** menu

Choose **Surface temperature...** option

Type **30.0** into **Temperature** box, then choose **Ok** button (or press RETURN key)

For this tutorial model, the surface temperature is assumed to be constant through the 0 to 25 Ma time points.

Choose **Settings** menu

Choose **Heatflow...** option

Type **80.0** into **Constant value** box, then choose **Ok** button (or press RETURN key)

For this tutorial model, the heatflow is assumed to be constant through the 10 to 25 Ma time points.

Repeat the procedure for the remaining 2 time-calibration points, i.e.

20.00 Ma
25.00 Ma

4.3.11 Printing a model report

Carry out the instructions given in section 4.2.10 for printing a model report.

Check that thermal parameter settings are in accordance with the procedures carried out above. If any are not, repeat the appropriate instructions.

4.3.12 Thermal calculation

The thermal parameters (conductivity, surface temperature and heatflow) are now loaded and HOTPOT is able to perform the thermal calculation.

Choose **Calculate** menu

Choose **Geothermal** option

On completion of the thermal calculation the HOTPOT Main Window is redisplayed.

4.3.13 Display of thermal model results

Carry out the instructions given in section 4.2.12 for displaying thermal model results.

The results are essentially the same as Model 1, except for the thermal results at 0 Ma (heatflow map replaces single-value heatflow). An example of this difference is given in Fig. 4.49, which illustrates a grid-node extraction of layer thermal history. Compare with Fig. 4.34. Note how the temperatures are the same at 25, 20 and 10 Ma, but different at the present day. Detailed differences of the present-day temperature grid maps are discussed in section 4.5.

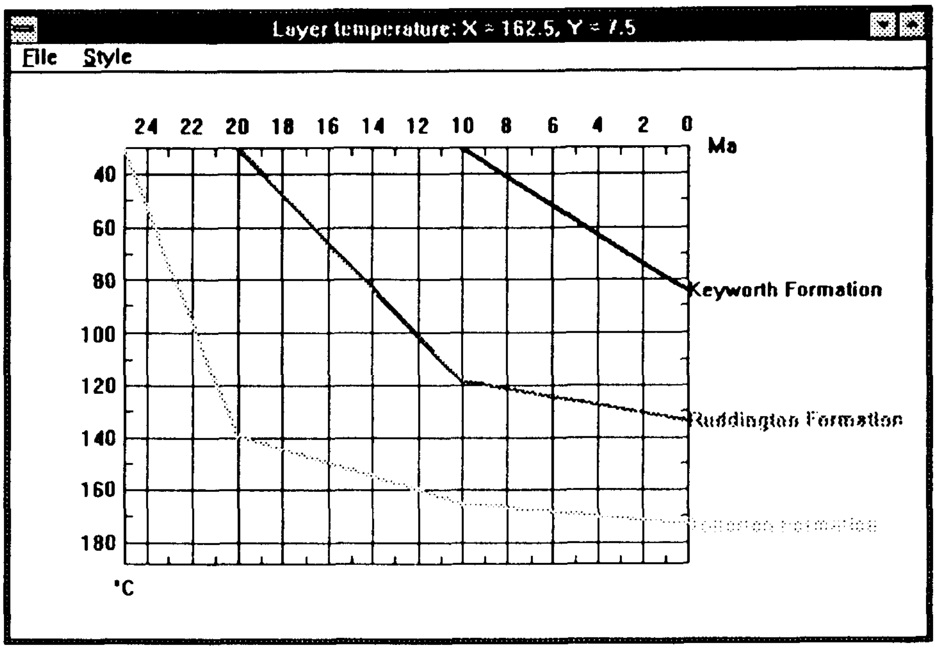


Figure 4.49

4.4 Tutorial Model 3

The third model shows how an eroded layer is incorporated into the model. Single-value constant heatflow is used for the thermal modelling, as in Model 1. The modelling session illustrates:

- the re-use of gridded data saved from previous modelling sessions (Model 2)
- the manual completion of a layer information dialogue for an eroded layer

(Note that we refer to some of the instructions given for Models 1 and 2 rather than repeat them here.)

4.4.1 Set the model title

Carry out the instructions given in section 4.2.1, but set the title to **Model 3** instead of Model 1

The title is shown on the main window caption bar.

4.4.2 Define the area of interest

Carry out the instructions given in Section 4.2.2, but use the file **model.aoi** instead of tutorial.aoi

model.aoi was the file saved when defining the area of interest during Model 2 (section 4.3.2).

4.4.3 Load auxiliary depth/density data

Carry out the instructions given in section 4.2.4

4.4.4 Load auxiliary depth/thermal conductivity data

Carry out the instructions given in section 4.2.7

4.4.5 Load the layer data

Keyworth Formation

Choose **File** menu

Choose **Layer...** option

The layer information dialogue opens.

Choose **Load...** button

A file selector dialogue opens.

Choose **kw.lay** from **Files** list

Layer information is loaded from file kw.lay, which was saved when entering layer information for the Keyworth Fm during Model 2 (section 4.3.5). The layer information dialogue is redisplayed, with the information shown.

Choose **Ok** button

The gridding window opens.

Choose the gridding window **File** menu

This drop-down menu is used to control input and output of gridded data.

Choose the **Load...** option

This is used to load a grid saved during a previous modelling session. A file selector dialogue opens.

Choose **keyworth.hpg** from **Files** list

This was the file saved when gridding the Keyworth Fm during Model 2 (section 4.3.5).

The file selector dialogue closes and HOTPOT loads information from the keyworth.hpg file. It then opens the Grid Confirmation dialogue, which shows both the name of the required grid and the name of the grid in the file you selected (these should be the same), and asks you to confirm that this is the grid you want to use, Fig. 4.50.

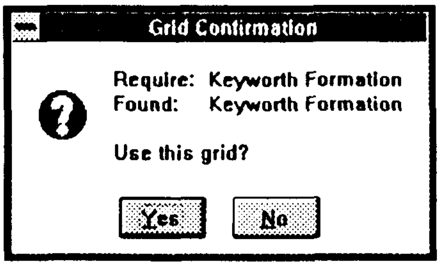


Figure 4.50

Choose **Yes** button

HOTPOT loads the grid data from the file into the layer grid and displays the grid map.

Choose **Accept** button

The grid is accepted and the gridding window closes. The HOTPOT Main Window shows the Keyworth Fm layer button; it is selected.

Choose **Settings** menu

Choose **Conductivity...** option

Select **Depth-variable** radio button

Links the depth/thermal conductivity table to the Keyworth Fm at 0 Ma (present day).

Choose **Ok** button

Bingham Member

You are now ready to load the next layer, the Bingham Member (the eroded part of the Ruddington Formation), of the model.

Choose **File** menu

Choose **Layer...** option

The layer information dialogue opens. The insertion point (flashing cursor) is in the Formation name *box.*

Type **Bingham Member** in **Formation name** box

This sets the name of the formation.

Press TAB key

Insertion point moves to the Lithology code *box.*

Type **SST=50% LST=50%** in **Lithology code** box

This defines the lithology of this layer to be 50% sandstone and 50% limestone (cf. Ruddington Fm). Note the space between the two component codes.

The component codes are given in the same order (SST first, LST second) as for the Ruddington Fm. This makes the decompaction and geothermal calculations more efficient as only one set of mixed lithology curves needs to be calculated for the two layers. ***Always adopt a standard order for specifying the components of mixed lithologies.***

Press TAB key

The TAB moves the insertion point to the Age at base *box.*

Type **14** in **Age at base** box, then press TAB key

This sets the age of the base of the layer to be 14 Ma.

The TAB moves the insertion point to the **Water depth** *box.*

Type **10** in **Water depth** box, then press TAB key

The water depth was 10 metres when deposition of the layer finished.

The TAB moves the insertion point to the **Eroded?** *check box.*

Press SPACEBAR

Pressing the SPACEBAR selects the **Eroded?** *check box, so marking this layer as eroded.*

The **Age eroded** *box is automatically enabled and the insertion point moved into it.*

Type **12** in **Age eroded** box

This sets the age of the onset of erosion to 12 Ma. Thus, deposition of the Bingham Member lasted from 14 Ma to 12 Ma and the erosional episode lasted from 12 Ma to 10 Ma, which is the age of the base of the overlying Keyworth Fm.

Select **m** radio button in **Isopach Units** group box.

The isopach data are in metres.

Fig. 4.51 shows the completed dialogue.

Choose **Data Files...** button in the **Isopach** box

A file-list dialogue opens for you to select digitised isopach data files for subsequent griddi.ig.

Choose **bingham.iso** from **Files** list

The full file path name c:\tutorial\bingham.iso *is copied into the* Selected files *list box, in the upper part of the dialogue.*

Choose **Ok** button

The file-list dialogue closes and the layer information dialogue is redisplayed.

Choose **Save...** button

A file selector dialogue opens.

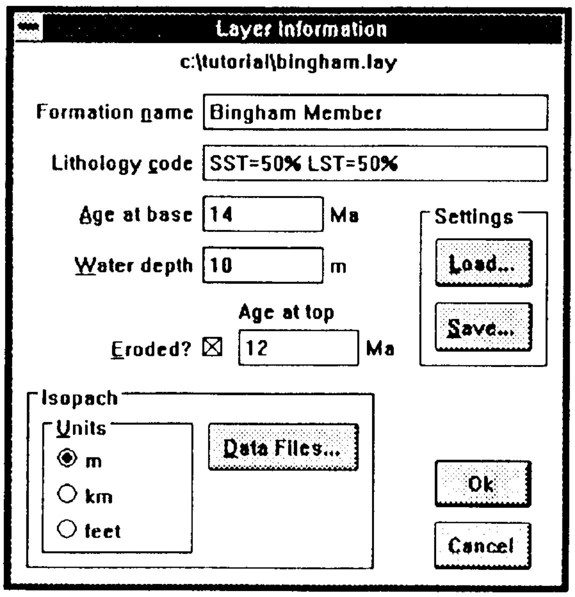


Figure 4.51

Type **bingham** then choose **Ok** (or press RETURN key)	*The file selector closes. The contents of the layer information dialogue (including the name of the isopach data file,* bingham.iso*) are saved in the file* bingham.lay *for use in a later modelling session.*
	The layer information dialogue remains open. The layer information file name is now shown below the dialogue caption bar, Fig. 4.51.
Choose **Ok** button	*The gridding window opens.*
Choose **Grid...** button	*The search radius dialogue opens.*
Type **0.17** into **Radius** box, then choose **Ok** button (or press RETURN key)	*The program grids the eroded isopach data with a 0.17° search radius and displays the map, Fig. 4.52. Experiment indicates that this is the smallest radius which generates no null nodes. Note the large area of zero nodes (i.e. no erosion), this is a necessary consequence of the anti-masking zero contours (Section 4.1.1).*
	[You may, of course, save this grid for future use, in the same way that you saved the layer isopach grids during Model 2.]

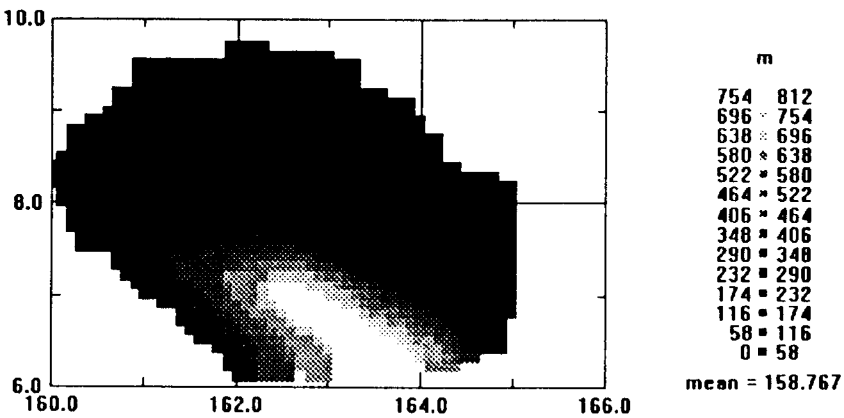


Figure 4.52

Choose **Accept** button	*The grid is accepted and the gridding window closes. The HOTPOT Main Window shows the Bingham Member button colour-coded magenta, to distinguish it as an eroded layer. It is selected (white text).*
Choose **Settings** menu	
Choose **Conductivity...** option	
Select **Depth-variable** radio button	*Links the depth/thermal conductivity table to the Bingham Member at 0 Ma (present day).*
Choose **Ok** button	

Ruddington Formation

Choose **File** menu	
Choose **Layer...** option	*The layer information dialogue opens.*
Choose **Load...** button	*A file selector dialogue opens.*
Choose **ruddinga.lay** from **Files** list	*Layer information is loaded from file* ruddinga.lay. *The layer information dialogue is redisplayed, with the information shown.*
Choose **Ok** button	*The gridding window opens.*
Choose the gridding window **File** menu	
Choose the **Load...** option	*A file selector dialogue opens.*
Choose **ruddinga.hpg** from **Files** list	*This was the file saved when gridding the Ruddington Fm during Model 2 (section 4.3.5).* *The file selector dialogue closes and HotPot loads information from the* ruddinga.hpg *file. It then opens the Grid Confirmation dialogue, which shows both the name of the required grid and the name of the grid in the file you selected (these should be the same), and asks you to confirm that this is the grid you want to use.*
Choose **Yes** button	*HotPot loads the grid data into the layer grid and displays the grid map.*
Choose **Accept** button	*The grid is accepted and the gridding window closes. The HotPot Main Window shows the Ruddington Fm button; it is selected.*
Choose **Settings** menu	
Choose **Conductivity...** option	
Select **Depth-variable** radio button	*Links the depth/thermal conductivity table to the Ruddington Fm at 0 Ma (present day).*
Choose **Ok** button	

Tollerton Formation

Choose **File** menu	
Choose **Layer...** option	*The layer information dialogue opens.*
Choose **Load...** button	*A file selector dialogue opens.*
Choose **toller.lay** from **Files** list	*Layer information is loaded from file* toller.lay. *The layer information dialogue is redisplayed, with the information shown.*

Choose **Ok** button	*The gridding window opens.*
Choose gridding window **File** menu	
Choose the **Load...** option	*A file selector dialogue opens.*
Choose **toller.hpg** from **Files** list	*HOTPOT loads information from the* toller.hpg *file (saved when gridding the Tollerton Fm during Model 2, section 4.3.5) and then opens the Grid Confirmation dialogue asking you to confirm that this is the grid you want to use.*
Choose **Yes** button	*HOTPOT loads the grid data into the layer grid and displays the grid map.*
Choose **Accept** button	*The grid is accepted and the gridding window closes. The HOTPOT Main Window shows the Tollerton Fm layer button below the Ruddington Fm button; it is selected.*
Choose **Settings** menu	
Choose **Conductivity...** option	
Select **Depth-variable** radio button	*Links the depth/thermal conductivity table to the Tollerton Fm at 0 Ma (present day).*
Choose **Ok** button	

4.4.6 Decompaction by backstripping

The HOTPOT Main Window shows the Keyworth Formation, Bingham Member (eroded), Ruddington Formation and Tollerton Formation buttons in the stratigraphic column. This indicates that all four model layers have been loaded and are ready for decompaction.

Carry out the instructions given in section 4.2.5 for decompacting the model.	*The thermal conductivity settings will be copied from the layers loaded to the layers created during backstripping.*

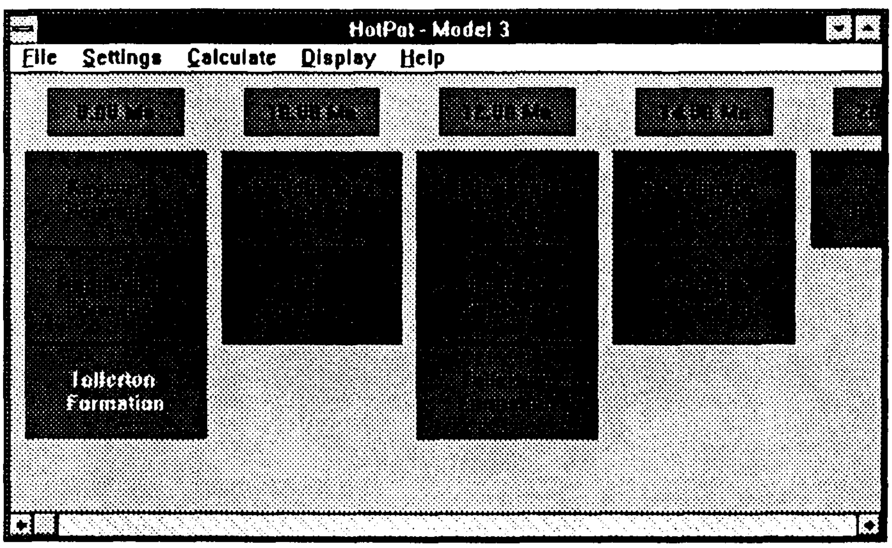


Figure 4.53

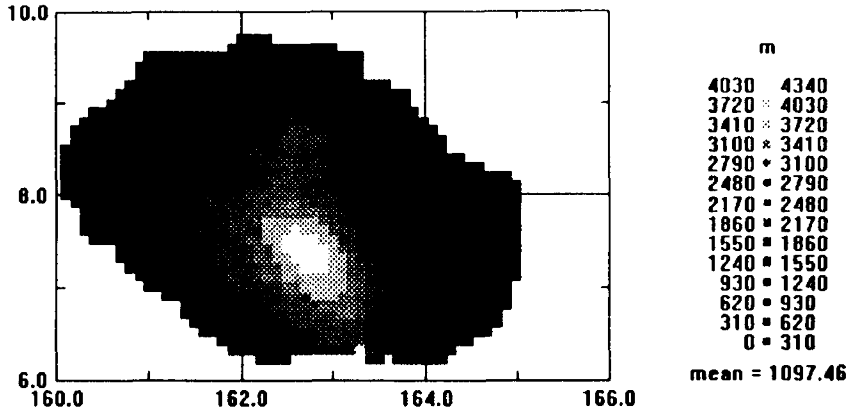


Figure 4.54

On completion, the HOTPOT Main Window should look similar to Fig. 4.53. The main window display for this model is quite large and, therefore, may exceed the size of the main window. In this case, scroll-bars will be displayed at the right and/or bottom sides of the window. These are used to move additional parts of the main window display into view, as required.

The displayed buttons, arranged as stratigraphic columns, graphically illustrate the stratigraphical evolution of the basin. They show the present day basin sequence and the decompacted sequences at stages in the basin history from 25 Ma to the present. Note the extra two time-calibration buttons (14.00 and 12.00 Ma), which are required to define the period of erosion. The eroded layer, the Bingham Member, is represented by a magenta-coloured eroded boundary line between the Keyworth and Ruddington Formations in the present-day (0.00 Ma) stratigraphic column. In the 10.00 Ma stratigraphic column, it is indicated by a magenta-coloured eroded surface line on top of the Ruddington Formation. In the 12.00 Ma column, the Bingham Member is restored as a normal layer; which has been removed by backstripping in the 14.00 Ma column.

4.4.7 Display of the backstripped data

Display options for the results of backstripping are the same as those in Section 4.2.6. Examples of grid map displays are given in Figs. 4.54 and 4.55. Fig. 4.54 shows the loaded thickness grid at 12 Ma, immediately prior to erosion. Fig. 4.55 shows the loaded thickness grid at 10 Ma, immediately after erosion. Note how the thicknesses in the southern part of the map are lower than those in

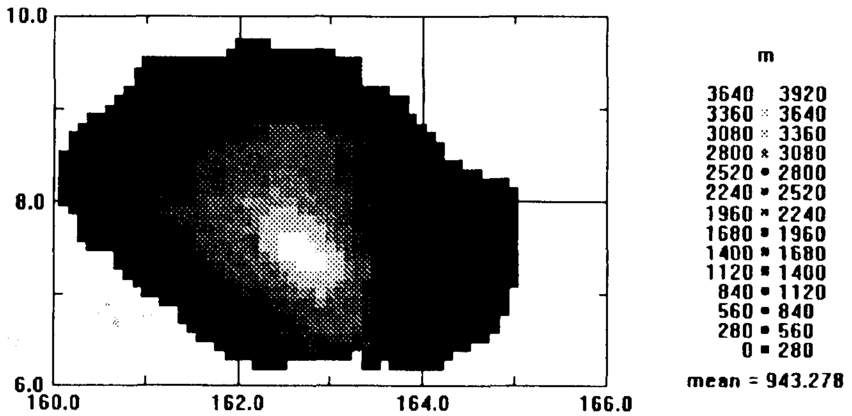


Figure 4.55

Tutorial Model 1 (Fig. 4.20), due to the compaction effects of the eroded layer. Thicknesses farther north, where there was no erosion are identical to those on Fig. 4.20.

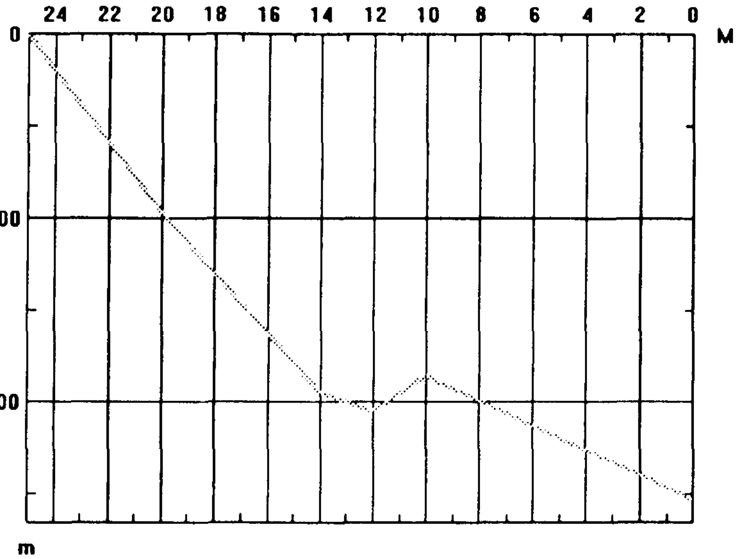


Figure 4.56

Results of grid-node extractions, at node 162.5°E, 7.5°N, are shown in Figs. 4.56 and 4.57. Fig. 4.56 shows the burial history of the base of the bottom layer (i.e. Tollerton Formation) and can be compared to Fig. 4.32, Model 1. Fig. 4.57 shows the burial histories of all four layers and can be compared to Fig. 4.33. Note the period of erosion and uplift between 12 and 10 Ma. Also note that the Bingham Member is shown only between start of deposition (14 Ma) and completion of erosion (10 Ma) on Fig. 4.57.

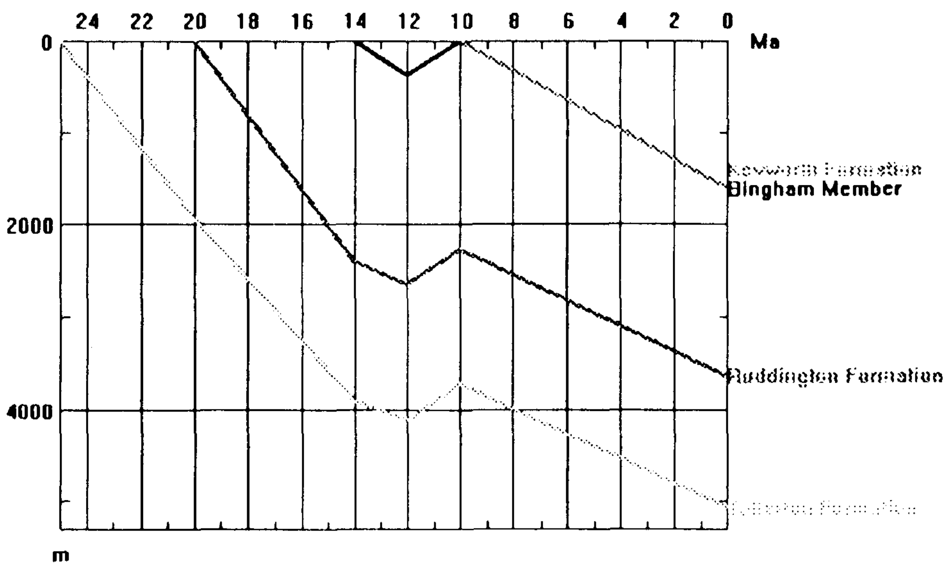


Figure 4.57

4.4.8 Setting age-related thermal parameters

Thermal computation can be carried out using either single-value constant heatflow (see Section 4.2.9) or spatially and time variant heatflow (see Sections 4.3.9 and 4.3.10) as required. When you set the age-related parameters, remember the two additional time-calibration points, at 12 Ma and 14 Ma, in this model.

4.4.9 Printing a model report

Carry out the instructions given in section 4.2.10 for printing a model report.

Confirm that thermal parameter settings are as intended.

4.4.10 Thermal calculation

Choose **Calculate** menu

Choose **Geothermal** option

4.4.11 Display of thermal model results

Display options for the thermal results are similar to those described in section 4.2.12 and are not described in detail as you should, by now, be familiar with the technique.

Example grid maps from a single-value constant heatflow thermal calculation (as in Model 1, Section 4.2.6) are given in Figures 4.58 and 4.59. These show the temperatures at the base of the Tollerton Formation at 12 Ma (Fig. 4.58) and 10 Ma (Fig. 4.59). Note the fall in temperature in the southern part of the basin between 12 and 10 Ma. Note also how the temperatures calculated here (Fig. 4.59) are lower than those obtained from Model 1 (Fig. 4.28). This is due to the compactional effects of the eroded layer, which decrease stratigraphical thicknesses and increase thermal conductivities. Figure 4.60 shows a grid-node extraction of layer thermal histories, compare this with Fig. 4.34 (Model 1).

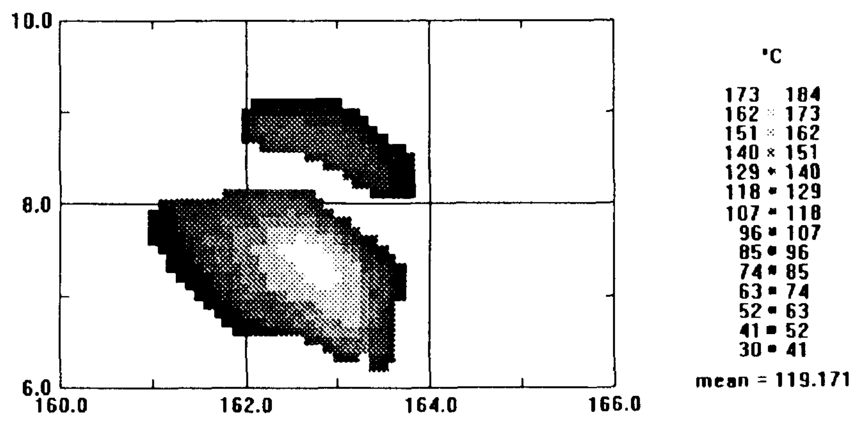


Figure 4.58

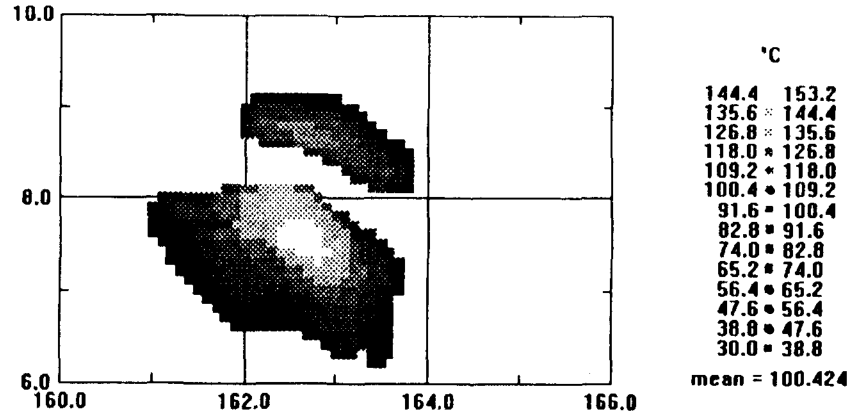


Figure 4.59

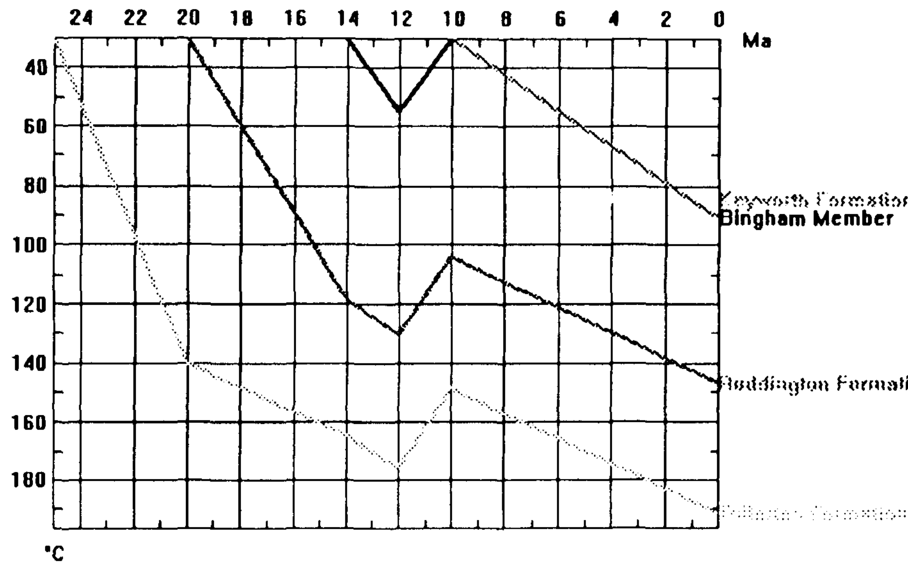


Figure 4.60

4.5 Interpretation

4.5.1 General statement

The accuracy of the above modelling of the imaginary basin, is constrained by the generalised nature of the isopach maps and by the practical necessity for demonstration purposes of grouping the strata into only three stratigraphical divisions. It is probable that, in a real basin, the sequence would be divided into many more units, with each isopach or structure contour map showing greater complexity and detail than those employed here, leading to more precise thermal models from the use of HOTPOT. Similarly, although the interpretation of the maps generated above can only be of a broad general nature, they suffice to illustrate the main principles of how results from more detailed HOTPOT-based modelling could be used in hydrocarbon exploration.

There is no single unique interpretation of the subsurface temperature maps as their meaning and value are dependent on the objectives of the user and the particular reasons for undertaking such modelling. This report is concentrating on the use of thermal modelling in hydrocarbon exploration and, therefore, the layer temperature maps with maturity scales (Figs 4.30-4.35) are the most relevant. These indicate the present-day and palaeo-locations of the 100°, 150° and 220° isotherms which are taken as defining the oil, gas and overmature zones. As the basin modelled is stated to have formed in the last 25 Ma years, this assumption is believed to valid. The influence of time on the maturity of any organic matter in such a young basin can be assumed to have been negligible.

4.5.2 Preliminary hydrocarbon prospectivity assessment

Many of the preliminary data provided about the basin are of relevance in hydrocarbon prospectivity. The following main conclusions can be drawn.

The **Tollerton Formation** is an almost totally argillaceous unit, deposited in an average water depth of 30 m. Therefore, this unit could have good source potential, but no certain inference can be drawn on likely kerogen type. Potential sandstone or limestone reservoir rocks are absent, or perhaps restricted to thin local basal and marginal clastic sediments. As the Tollerton Formation was laid down at a time of syn-extensional subsidence, some closed structural traps could have formed during deposition, but the potential for stratigraphical traps seems to be limited.

The **Ruddington Formation** comprises sandstone and limestone in equal proportions laid down in an average water depth of 10 m. This suggests a shallow marine sequence with little source potential. Both sandstones and limestones could provide suitable reservoirs. The Ruddington Formation forms part of the post-extension sequence and syn-depositional faulting is stated to have largely ceased during deposition of this unit, so few structural traps can have formed at this time. However, a sequence of alternating marine sandstones and limestones could provide the location for stratigraphical traps.

A period of uplift and erosion followed the deposition of the Ruddington Formation. It is likely that structural traps were generated at this time, particularly within the Ruddington Formation in which the main potential reservoirs occur, but the lack of argillaceous rocks suggests that the reservoirs may not be well sealed.

The **Keyworth Formation** is a sandstone unit laid down close to sea level during the later stages of post-extension subsidence. The general lack of argillaceous rocks indicates that this unit can have no source potential. The sandstones could have good reservoir characteristics, but the lack of interbedded sealing shales and the limited tectonic deformation suggest that there are no closed sealed structures within this layer.

To summarise:

1. Potential source rocks probably occur only in the Tollerton Formation.

2. Structural traps with suitable reservoir rocks are largely restricted to the Ruddington Formation.

3. The main potential for stratigraphical traps is in the Ruddington Formation.

4. The main period of structural trap generation was at the end of deposition of the Ruddington Formation, but some closed structures could have formed during the syn-extension subsidence contemporary with the Tollerton Formation.

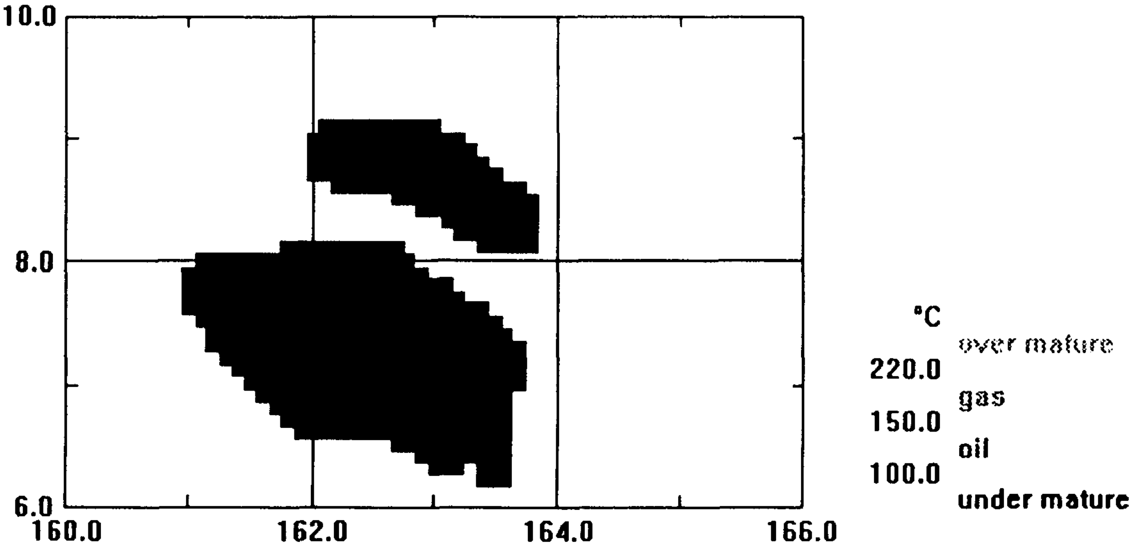


Figure 4.61: Tollerton Formation at 20 Ma (Model 1)

4.5.3 The significance of the temperature maps

Figure 4.61 is a pseudo-maturity map of the base of the Tollerton Formation at 20 Ma from Model 1. It suggests that any hydrocarbon source rocks, particularly in the lower part of the Tollerton Formation could have begun to generate oil towards the close of syn-extension subsidence at 20 Ma. However, because of the lack of suitable reservoir rocks and sealed structures at this time, it must be assumed that most hydrocarbons formed were able to escape.

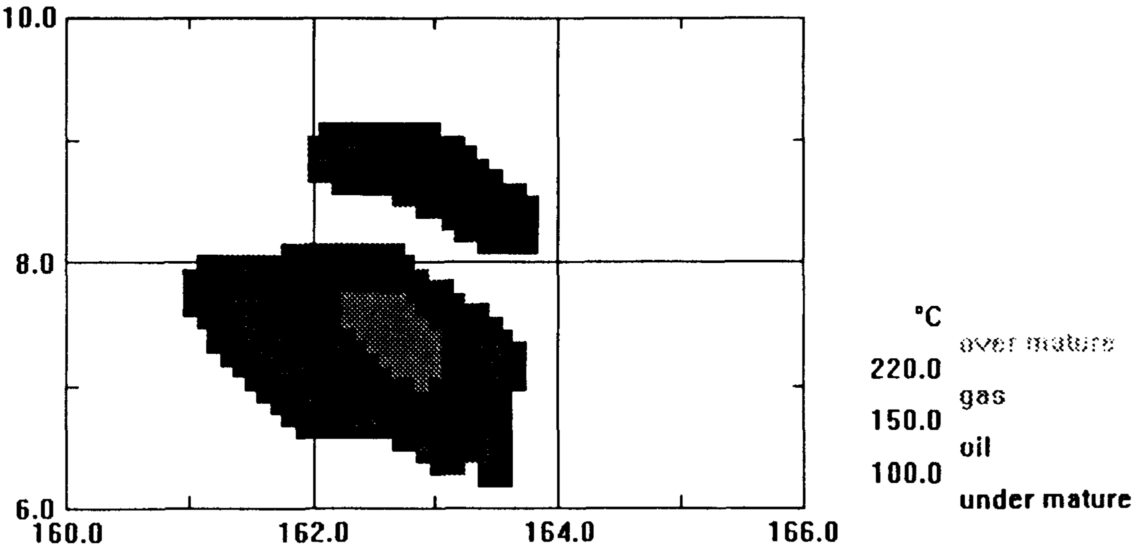


Figure 4.62: Tollerton Formation at 10 Ma (Model 1)

By the end of Ruddington Formation deposition, at 10 Ma, much of the Tollerton Formation was in the oil generating zone and, in some deeper central areas, some gas could have been generated (Fig. 4.62, from Model 1). Fig. 4.63, also from Model 1, shows that the Ruddington Formation had reached temperatures in the oil generating zone; however, as its lithology indicates a lack of source potential, it is unlikely that any oil actually formed. Although the presence of suitable reservoir rocks in the Ruddington Formation can be anticipated, the probable lack of closed structures suggests that most

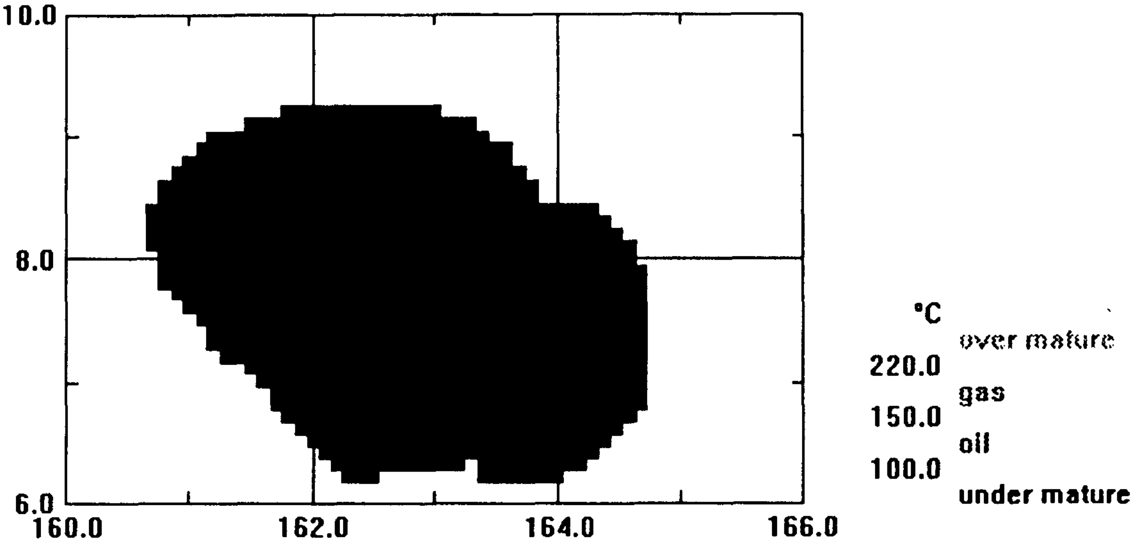


Figure 4.63: Ruddington Formation at 10 Ma (Model 1)

of the hydrocarbons generated continued to escape, unless significant numbers of stratigraphical traps were present.

It is a reasonable expectation that sealed closed structural traps were formed during the post-Ruddington Formation deformational event and that significant hydrocarbon entrapment began. The present-day temperature maps (Figs. 4.64 to 4.66) provide an qualitative estimate of the type and areal extent of hydrocarbon generation since the main structural traps were formed, and the likely broad distribution of oil and gas in the sandstone reservoir rocks of the Ruddington Formation.

As the main source potential is confined to the Tollerton Formation, the maps (Fig. 4.64) suggest that gas will probably form a major proportion of any reservoired hydrocarbons, particularly in the central parts of the basin. However, there are also significant areas in the Tollerton Formation where, if suitable kerogens were present, oil could have been generated, before migration and entrapment in the Ruddington Formation.

Comparison of the predicted temperatures derived from a single basin-wide value for heatflow (Figs. 4.64a, 4.65a, 4.66a), with those obtained using the heatflow map (Figs. 4.64b, 4.65b, 4.66b), suggests that the former generally predict lower present-day temperatures and, hence, lower current levels of maturity of organic matter. Provided that the heatflow map is based on good data, and can be employed with confidence, then the temperature predictions, based on its inclusion in the calculations, are thought to provide the best possible estimates. However, it must always be remembered that the current heatflow distribution is probably influenced by groundwater convection, and that the heatflow pattern may have been significantly different during earlier periods of basin history, particularly prior to the post-Ruddington Formation uplift and erosion. The present heatflow pattern could be of relatively recent origin, in which case, the use of a single basin-wide value may be more appropriate.

The effects of allowing in the modelling for the erosion of the topmost part of the Ruddington Formation (i.e. the Bingham Member in Model 3) are shown in Figs. 4.67 and 4.68. Both the Ruddington and Tollerton Formations were more deeply buried in the south than allowed for in Models 1 and 2, considered above. These, therefore, underestimated the temperatures and organic maturities attained, and the full extent of hydrocarbon generation prior to the post-Ruddington Formation deformation and erosion.

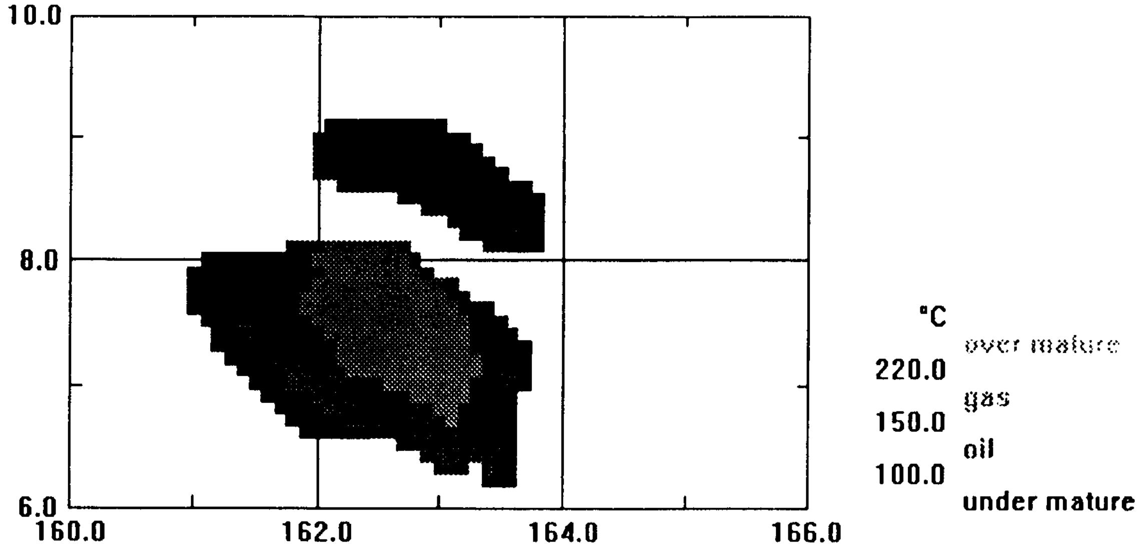


Figure 4.64a: Tollerton Formation at 0 Ma (Model 1)

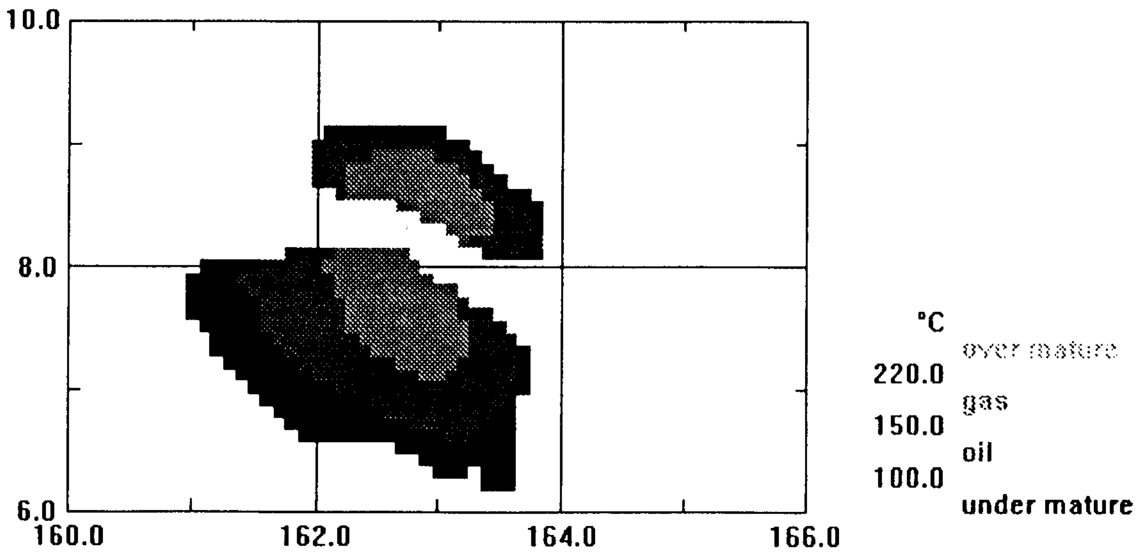


Figure 4.64b: Tollerton Formation at 0 Ma (Model 2)

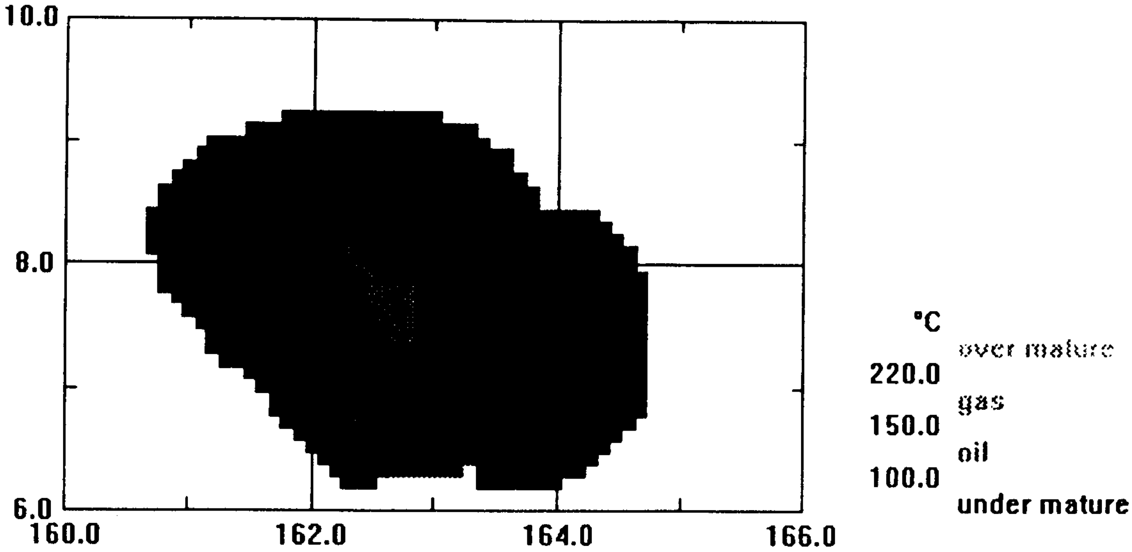


Figure 4.65a: Ruddington Formation at 0 Ma (Model 1)

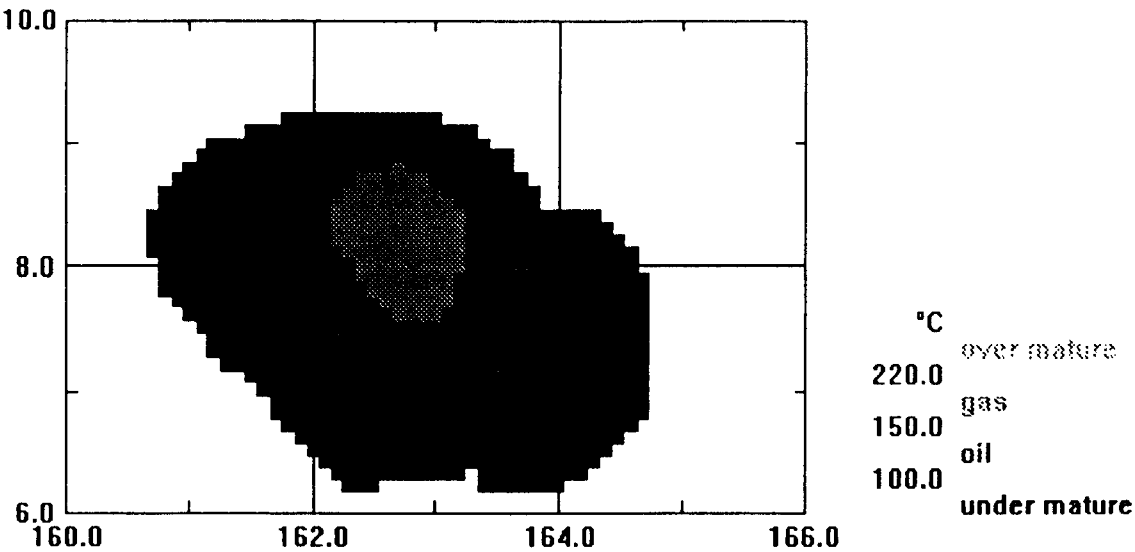


Figure 4.65b: Ruddington Formation at 0 Ma (Model 2)

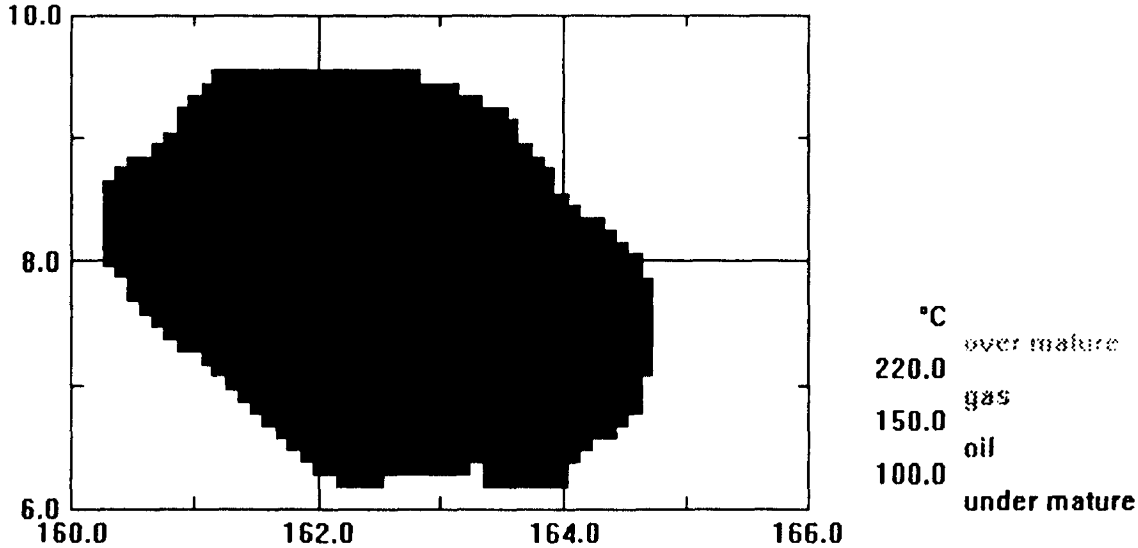


Figure 4.66a: Keyworth Formation at 0 Ma (Model 1)

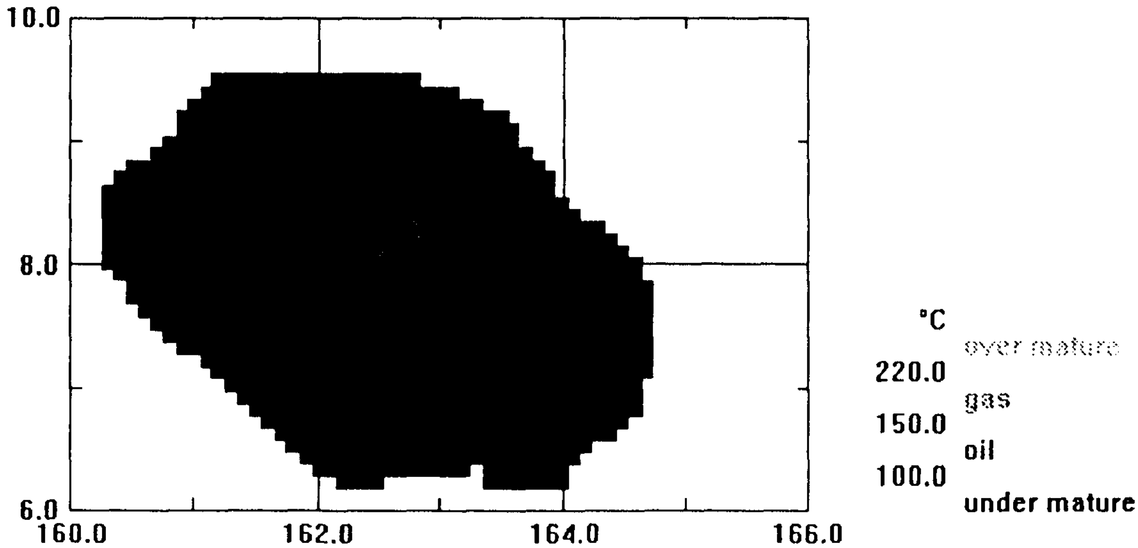


Figure 4.66b: Keyworth Formation at 0 Ma (Model 2)

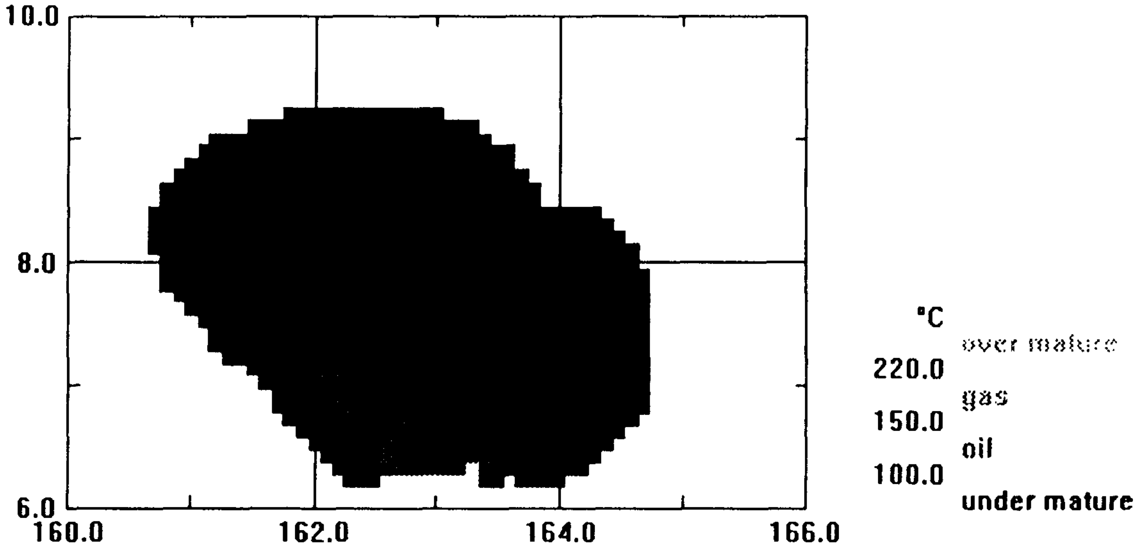


Figure 4.67: Ruddington Formation at 12 Ma (Model 3)

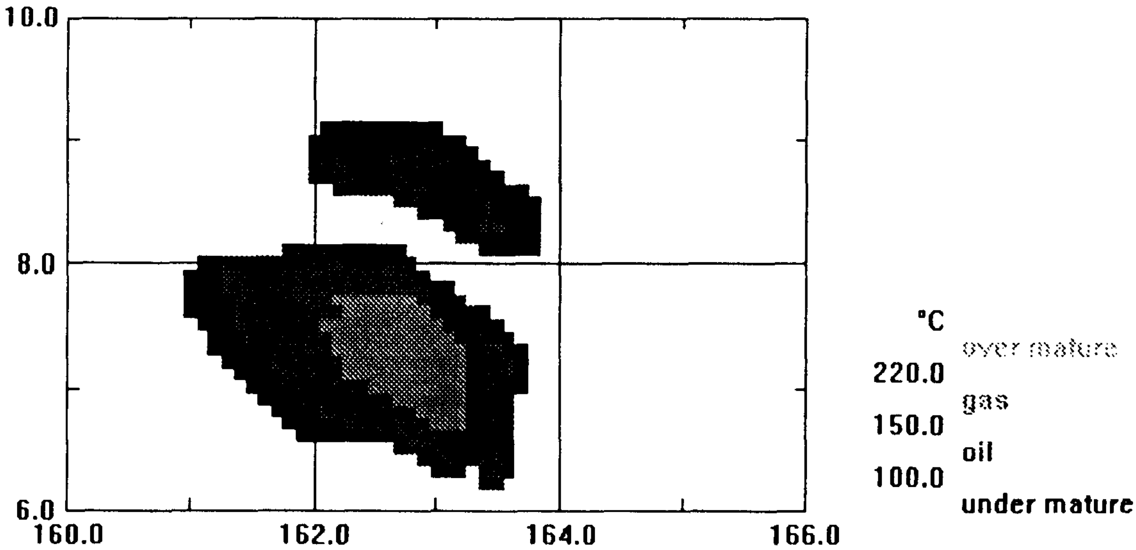


Figure 4.68: Tollerton Formation at 12 Ma (Model 3)

SECTION 5

Reference to HOTPOT version 3.0 for Windows

5.1 Windows, menus and dialogues

HOTPOT uses four types of windows for its displays:

- the HOTPOT Main Window
- Graph Display Windows
- Grid Display Windows
- the Gridding Window

Each window type has a menu bar containing drop-down menus. The following sections describe how these window types and their menus are used.

Several dialogues are used to obtain information from the user during program operations. Some of these (the File Selector dialogue, the File List dialogue, the Print dialogue, the Printer Setup dialogue and the Progress Reporting dialogue) are common to several operations and are described separately. The other dialogues are described during the description of related menu items.

5.2 General information

The following Windows conventions have been used in the design of the HOTPOT user interface:

Any menu option shown in black text is enabled and can be chosen. Any menu option shown in grey text is disabled and cannot be chosen.

Check marks (√) are used in conjunction with some menu items:

√ to indicate a currently selected option

√ to indicate to the user that an operation associated with the item has been performed successfully, where no other visual confirmation would be available

Buttons with their text shown in black are enabled and can be chosen. Buttons with their text shown in grey are disabled and cannot be chosen.

An ellipsis (a sequence of three periods ...) is appended to the text label of any menu item or button which, when chosen, invokes a dialogue box.

All dialogues have a system menu button at the left end of their caption bars. The system menu provides an alternative method for users to move and close the dialogue. Choosing **Close** from a dialogue system menu is the same as choosing that dialogue's **Cancel** button.

5.3 Common dialogues

5.3.1 The File Selector dialogue

This is used whenever HOTPOT requires the user to select a single file so that data can be saved to disk or read from disk. It is similar in operation to the file selector dialogues used by many Windows applications. Figure 5.1 shows an example of the HOTPOT file selector dialogue.

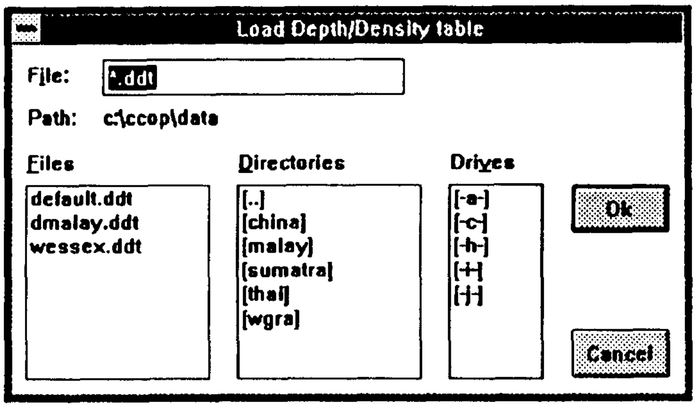


Figure 5.1

The dialogue caption, in the top border will briefly explain what sort of file is required and what operation is being performed.

The **Path** text shows the current directory.

The **File** edit box shows either a suggested file name or a wild card file specification, used in conjunction with the **Files** list box. Text in this edit box may be selected and then edited using the keyboard.

The **Files** list box shows files in the current directory (**Path**) matching the name in the **File** edit box.

The **Directories** list box shows a list of alternative directories. The directory **[..]** is the directory above the current directory in the file hierarchy; any other directories are below the current directory.

The **Drives** list box shows a list of alternative disk drives. The use of floppy disks or RAM disks with HOTPOT is not recommended. Disk drives attached to a local area network server can be used.

Choosing the **Ok** button will action the selections in the dialogue. If these form a valid file name, that file will be used for the current operation and the dialogue will close. Otherwise, the fields of the dialogue will be updated with the selections and the dialogue will continue. Choosing an item in a list box is the same as selecting that item then choosing the **Ok** button.

Choosing the **Cancel** button will close the dialogue and cancel the current operation of the program safely.

5.3.2 The File List dialogue

This is used whenever HOTPOT requires the user to select a list of one or more files so that data can be read from disk. It is similar in operation to the multiple file selector dialogues used in other Windows applications. Figure 5.2 shows an example of the HOTPOT file list dialogue.

The dialogue caption, in the top border will briefly explain what sort of files are required and what operation is being performed.

The **Path** text, **File** edit box and **Files**, **Directories** and **Drives** list boxes, in the lower part of the dialogue, perform the same functions as they do in the File Selector dialogue.

Choosing the **Select** button will action the selections in the **Path** text, **File** edit box and **Files**, **Directories** and **Drives** list boxes. If these form a valid file name, that file name will be copied to the **Selected files** list box in the upper part of the dialogue. Otherwise, the fields of the dialogue will be updated with the selections. The dialogue will continue. Choosing an item in one of these list boxes is the same as selecting the item then choosing the **Select** button.

The **Selected files** list box in the upper part of the dialogue lists the full path names (i.e. combined disk drive letter, directories and filename) for each file currently included in the file list.

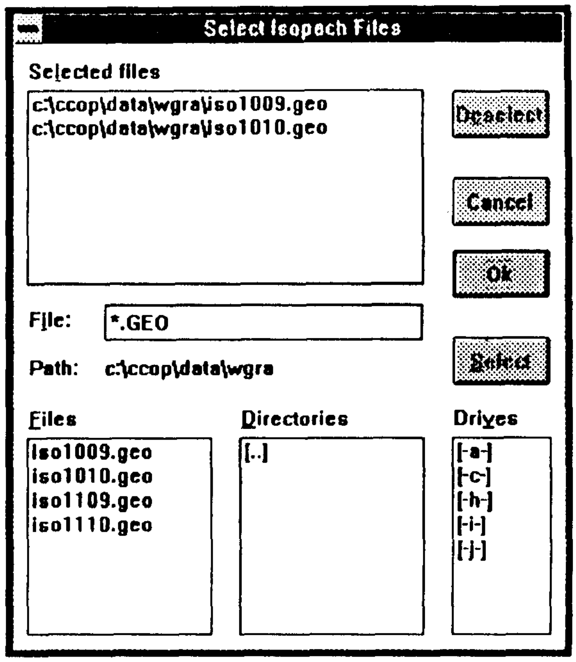


Figure 5.2

Items in the **Selected files** list box may be selected (hold down the CTRL key while making multiple selections) and then removed from the list by choosing the **Deselect** button. Choosing an item in this list box is the same as selecting the item then choosing the **Deselect** button. This facility is provided in case incorrect names are inadvertently copied into the file list.

Choosing the **Ok** button will use the list of files in the **Selected files** list box to perform the current operation of the program and close the dialogue.

Choosing the **Cancel** button will close the dialogue and cancel the current operation of the program safely.

5.3.3 The Print dialogue

This dialogue is displayed when HotPot is sending data to the Windows Print Manager (Fig. 5.3). The Print Manager is used by Windows to control access to the system's printer and to queue documents to be printed. The Print Manager is described in Chapter 6 of the *Microsoft Windows User's Guide.*

The text in the dialogue box will describe the document being sent to the Print Manager. The user may cancel the operation by clicking the **Cancel** button in the dialogue. In this case the document will not be printed and the dialogue will be closed.

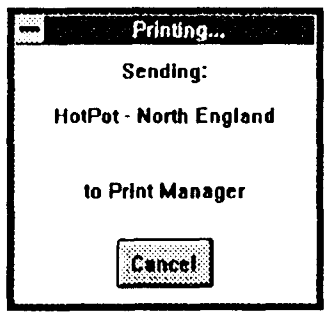


Figure 5.3

The dialogue will automatically close once the document has been sent to the Print Manager. Control of the printing operation then passes to the Print Manager.

Any problem encountered as data is sent to the Print Manager or from the Print Manager to the printer will be reported by a message dialogue. Acknowledge such a message by choosing its dialogue **Ok** button; depending on the type of problem, this may also cancel the print operation.

5.3.4 The Printer Setup dialogue

This is a dialogue which allows printers to be selected and configured.

All printers installed on the computer system (including any attached to the network in the case of networked computers) and configured for Windows use will be listed in the dialogue, e.g. Figure 5.4. The currently selected printer is shown highlighted in the list. An alternative may be selected from the list.

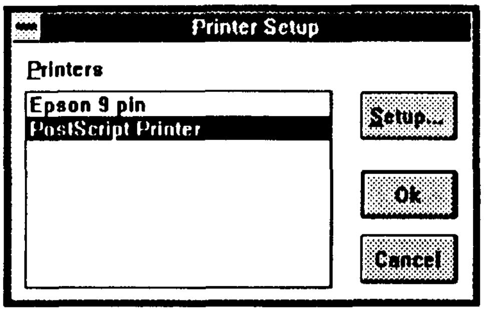


Figure 5.4

Choosing the **Setup...** button in this dialogue will open the printer driver configuration dialogue for the selected printer. This is part of the Windows printer driver software, supplied by either Microsoft or the printer manufacturer. Refer to the appropriate documentation for a description of printer configuration.

Only Windows 3 printer drivers may be configured in this way. If the **Setup...** button does not open a configuration dialogue, this means that the printer driver is not Windows 3 compliant. Windows 2 printer drivers (which will work with Windows 3) must be configured from the Windows Control Panel program instead.

Choosing the **Ok** button will close the dialogue and effect any changes made to the printer selection or configuration. Such changes apply only to the current instance of the HOTPOT program, and may be limited to some of the window types used by HOTPOT (see under **File** menu, **Printer setup...** option in each of the window type descriptions, sections 5.4, 5.5 and 5.6, for more information).

Choosing the **Cancel** button will close the dialogue without changing either the selected printer or its configuration.

5.3.5 The Progress Reporting dialogue

This dialogue is displayed when HOTPOT is carrying out a lengthy data processing operation. It is provided so that the user is aware of what data processing is being done and how near to completion it is. Figure 5.5 shows an example.

The text in the dialogue will describe: the data processing operation being performed, which data are being used and what percentage of the data have been processed.

For certain data processing operations, the **Cancel** button in the dialogue may be chosen to cancel the data processing operation; for example, if the text messages indicate an error.

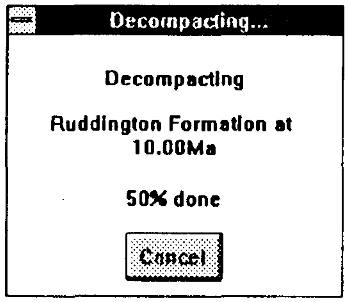


Figure 5.5

5.4 The HOTPOT Main Window

The HOTPOT Main Window is used to control the overall operation of the program. The main window is moveable and sizeable and may be minimized or maximized. Closing this window, by choosing the **Close** option from its system menu, exits the program, closing all subsidiary windows and releasing all system resources used.

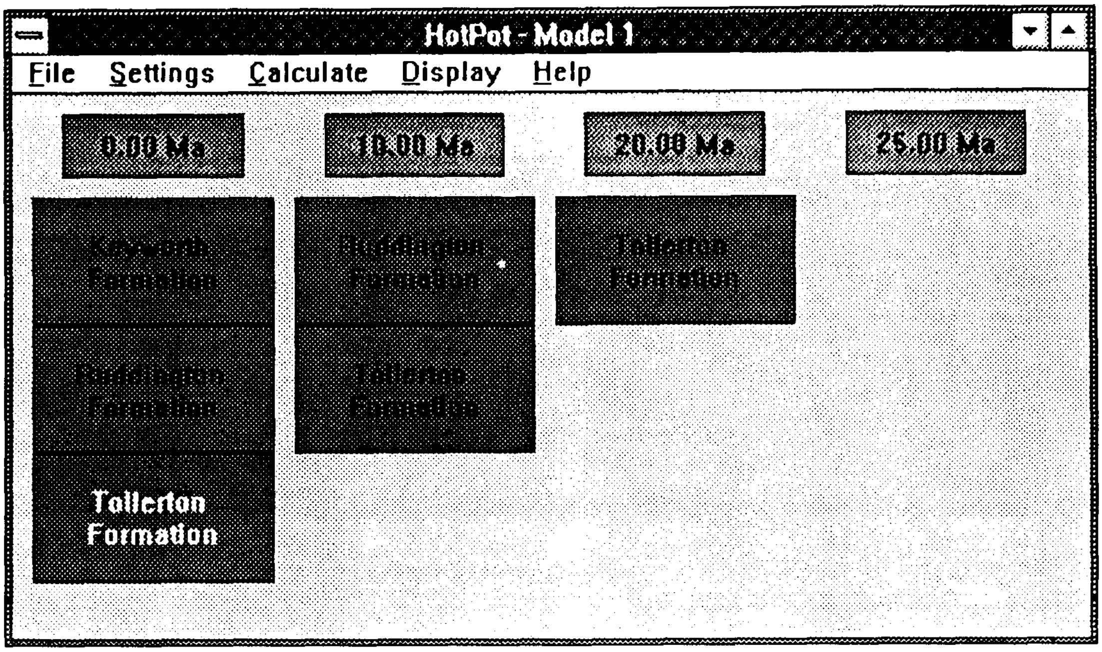


Figure 5.6

The HOTPOT model is displayed symbolically using colour-coded buttons, arranged to simulate stratigraphic columns, on the light-grey window background, Figure 5.6. The colour coding scheme is:

Before backstripping

Cyan	Normal layer
Magenta	Eroded layer
Black boundary line	Normal boundary

After backstripping

Yellow	Stratigraphic column age
Cyan	Normal layer
Black boundary line	Normal boundary
Magenta boundary line	Erosional boundary

When the stratigraphic column display exceeds the size of the window border, scroll bars are switched on.

The buttons are used to select items from the model for setting parameters and for display in subsidiary windows. The currently selected button is indicated by a white text label.

The layer and age buttons displayed in the main window may be selected by using the keyboard as well as by using the mouse. The TAB and BACKTAB (i.e. SHIFT + TAB) keys move the focus by one button at each press. The button having focus is indicated by a contrasting-colour box drawn around its text label. TAB moves the focus down the layer buttons of a column, then to the age button of that column and then to the top layer button of the next oldest column. BACKTAB moves the focus in the opposite direction. The SPACEBAR is pressed to select the button having focus. Keyboard control allows the Windows Recorder program to be used more effectively to record and replay HOTPOT sessions, e.g. for demonstrations or presentations.

The menu bar of the HOTPOT Main Window contains the following items:

File	loading, saving and printing data
Settings	setting program and data parameters
Calculate	performing calculations on the model
Display	displaying data from the model
Help	obtaining information about program operation

File

This is a drop-down menu with the following options:

New	delete current model and start a new one
Depth/Density...	load depth/density data
Depth/Conductivity...	load depth/thermal-conductivity data
Topography...	add a topographic surface to the model
Layer...	add a stratigraphic layer to the model
Heatflow...	add heatflow map data to the model
Annotation...	select a list of display annotation files
Print	print a description of the current model
Printer setup...	select or configure printers
Exit	exit from the HOTPOT program

File : New

May be chosen at any time. If there is a model currently in HOTPOT, a message dialogue will be displayed, asking for confirmation before deleting the model.

Choose the **Yes** button to delete the model and reset the program, ready to input a new model.

Choose the **No** button to resume working with the current model.

File : Depth/Density...

May be chosen at any time prior to performing the decompaction calculation. A depth/density table must be loaded in order to perform the decompaction calculation. When a depth/density data table is loaded a checkmark (√) is displayed next to this menu item.

When this menu option is chosen, HOTPOT will display a file selector dialogue for *.ddt (depth/density table) files. Use this dialogue to locate the correct disk drive, directory and file. Then choose the **Ok** button to load the data table from file into program memory. An hourglass cursor will

be shown during this operation.

If depth/density data are being displayed in a Graph Display Window (section 5.5) when a new table is loaded, the graphic display will be automatically updated. This is a useful method for browsing through the available depth/density table files.

File : Depth/Conductivity...

May be chosen at any time. A depth/conductivity table must be loaded in order to use depth-varying thermal conductivity data when performing a thermal calculation. When a depth/conductivity data table is loaded a checkmark (√) is displayed next to this menu item.

When this menu option is chosen, HOTPOT will display a file selector dialogue for *.dkt (depth/thermal conductivity table) files. Use this dialogue to locate the correct disk drive, directory and file. Then choose the **Ok** button to load the data table from file into program memory. An hourglass cursor will be shown during this operation.

If depth/conductivity data are being displayed in a Graph Display Window (section 5.5) when a new table is loaded, the graphic display will be automatically updated. This is a useful method for browsing through the available depth/conductivity table files.

File : Topography...

May be chosen when an area of interest has been defined and prior to performing the decompaction calculation. A topographic surface must be defined in order to perform the decompaction calculation in depth mode, as it is required to calculate the thickness of the topmost layer. When a topographic surface is defined a checkmark (√) is displayed next to this menu item.

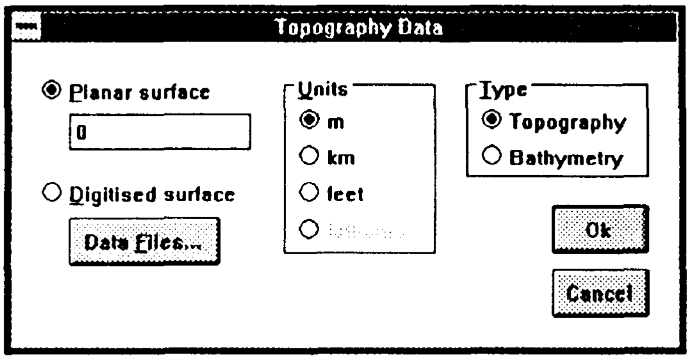


Figure 5.7

Choosing this menu option displays the dialogue (Fig. 5.7) which controls the definition of the surface.

The group of radio buttons labelled **Type** give a choice of topographic or bathymetric specification. Select **Topography** for a conventional topographic surface where heights above mean sea level (MSL) are represented by positive numbers and depths below MSL by negative numbers (used with onshore data). Select **Bathymetry** for a conventional bathymetric surface where depths below MSL are represented by positive numbers and heights above MSL by negative numbers (used with offshore data).

The group of radio buttons labelled **Units** specify the units of measure for the data. Select one of the available options, which are: metres (**m**), kilometres (**km**), **feet** and, for bathymetric data only, **fathoms**.

Select the **Planar surface** radio button to define a flat surface at a constant elevation with respect to MSL. Then enter the elevation value into the **Planar surface** edit box. The elevation value entered will be interpreted with respect to the **Units** and **Type** selections.

Select the **Digitised surface** radio button if digitised contour data are available. Then choose the **Data Files...** button to open a file list dialogue and select the files containing the digitised contour

data. The formats which may be used for digitised contour data files are described in Appendix II.2.

Choose the **Ok** button to complete the dialogue. If the digitised surface option was selected, HOTPOT will open a Gridding Window for the data in the digitised contour files to be gridded. (Section 5.7 describes the data gridding window.) Otherwise, a planar surface will be calculated.

Choose the **Cancel** button to close the dialogue without defining a topographic surface.

File : Layer...

May be chosen when an area of interest has been defined and prior to performing the decompaction calculation. The model must have at least one layer in order to perform the decompaction calculation.

Choosing this item will display the Layer Information dialogue, Figure 5.8. This dialogue has fields for entering the following information about the layer.

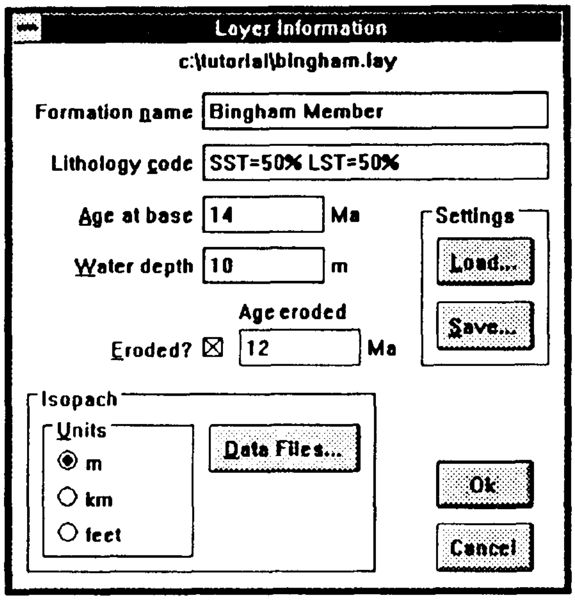


Figure 5.8

Formation name: The geological formation name, which will be used to identify the layer. Text in the edit box will scroll left when the right-most limit of the box is reached. Any printing characters may be used and spaces may be included in the name.

Lithology code: The encoded lithological description, which will be used to cross-reference depth/density and depth/thermal conductivity tables. The primary lithology codes used here must match those used in the tables. (The supplied tables use the following primary lithology codes: SST for sandstone, LST for limestone, MDSLST for mudstone/siltstone, OPSHAL for overpressured shale.) Proportions of primary lithologies may be assigned in percent; percentages must add up to 100. Primary lithologies are separated by spaces. Text in the edit box will scroll left when the right-most limit of the box is reached. Examples are:

SST	pure sandstone (same as SST=100%)
SST=75% LST=25%	calcareous sandstone
MDSLST=20% LST=80%	muddy/silty limestone
SST=85% OPSHAL=15%	sandstone with overpressured shale

Age at base: The age of the base of the layer in Ma (millions of years before present). Decimal fractions are permitted.

Water depth: The water depth, in metres, when deposition of the layer finished. This value is used in the calculation of tectonic subsidence (see Section 2.2.1).

Eroded? Select this check box if the isopach data represent a layer which has been eroded. In this case, the **Age eroded** edit box will be enabled. Enter the age at which erosion commenced, in Ma (millions of years before present), decimal fractions are permitted. The difference between this age and the age of the base of the layer above will determine the duration of the period of erosion.

Isopachs (isopach mode) or **Depths** (depth mode): This is a group of controls for linking isopach or depth data files to the layer information. Select one of the **Units** radio buttons to specify the units of measure (**m** metres, **km** kilometres or **feet**) used for the isopach or depth values. Choose the **Data**

Files... button to display the a file list dialogue and select the digitised isopach or depth data files for this layer (at least one file must be selected). The formats which may be used for isopach or depth data files are described in Appendix II.2.

Layer information entered in this dialogue may be saved for later use by choosing the **Save...** button. Previously saved layer information may be recalled by choosing the **Load...** button. Both these actions will open a file selector dialogue for *.lay files, which are used to store Layer Information dialogue entries. The names of isopach or depth data files (from the file list dialogue) are also saved in the .lay files. When a .lay file is loaded, HOTPOT checks to ensure that all specified data file names are valid; if any are not, the whole list of data files is ignored.

Choosing the **Ok** button will complete the Layer Information dialogue and open a data gridding window, for the data in the isopach or depth files to be gridded. The use of the data gridding window is described in section 5.7. If the data gridding operation is successful, the data will be added to the model and a button, bearing the **Formation name**, will be shown on the HOTPOT Main Window (Fig. 5.6). The button will be coloured cyan for a normal layer or magenta for an eroded layer. The layer buttons are shown as a stratigraphic column, ordered by age, with the youngest at the top.

Choosing the **Cancel** button will cancel the **Layer...** operation and return to the HOTPOT Main Window.

File : Heatflow...

May be chosen at any time after the decompaction calculation has been performed and an age button has been selected. It is used to compute a heatflow grid from digitised heatflow map data.

The **Heatflow Files** file list dialogue is displayed for the user to select one or more data files containing digitised contours from a heatflow map. The formats which may be used for digitised contour data files are described in Appendix II.2.

Choosing the **Ok** button will close the dialogue and open the Gridding Window so that the user may grid the data. The use of the data gridding window is described in section 5.7. The grid, if successfully computed, will be attached to the selected boundary age in the model.

Choosing the **Cancel** button will return the user to the Main Window without computing a heatflow grid.

File : Annotation...

May be chosen at any time.

The Annotation Files file list dialogue is displayed for the user to select a list of annotation files. Annotation files are used in conjunction with the **Annotate** option in the **Style** menu of Grid Display Windows (section 5.6) to overlay line-work (e.g. a coastline) on displayed grid maps. The format of annotation files is described in Appendix II.3.

Choosing the **Ok** button will close the dialogue and, if the file list contains any files, the **Annotation...** menu option will be check marked.

Choosing the **Cancel** button will close the dialogue and leave any existing file list unchanged.

File : Print

May be chosen at any time.

This produces a formatted report of the current state of the program and model. The report is sent to the printer via the Windows Print Manager. (The printer and its configuration may be altered by choosing the **Printer setup...** option from this menu.) A Print dialogue is displayed while this option is being processed.

The content of the report will depend on the status of HotPot. Details will include (as appropriate):

- name of depth/density table file
- name of depth/thermal conductivity table file
- area of interest specification
- summary of stratigraphy (layer information) including names of isopach or depth data files
- summary of basin history, including thermal parameter settings and names of heatflow contour files

File : Printer setup...

May be chosen at any time.

This invokes a dialogue which allows printers to be selected and configured. (See description of Printer Setup dialogue under common dialogues, section 5.3.4.)

When a Windows 3 printer driver is in use, HotPot will, by default, print text reports using portrait page orientation and graphics using landscape page orientation. If the page orientation is changed by choosing **Printer setup...** from the HotPot Main Window **File** menu, only the orientation of text reports will be changed.

File : Exit

May be chosen at any time. This exits (or quits) the HotPot program and returns to the Windows desktop. If a model is in use, a dialogue will open, prompting you to confirm your intention to delete the model and exit. Choose the **Yes** button to exit. Choose the **No** button to resume work on the model. (See also: Section 3.8 Quitting HotPot.)

Settings

This is a drop-down menu with the following options:

Title...	main window caption text and model name
Depth mode	layer data entered as depths
Isopach mode	layer data entered as isopachs [default]
Area of Interest...	area of interest (map and grid limits)
Top age...	age of top of top layer
Surface temperature...	surface temperature at selected age

Heatflow...	heatflow at selected age
Conductivity...	thermal conductivity of selected layer

Settings : Title...

May be chosen at any time.

This changes the model title, shown in the caption on the HotPot main window. A dialogue is displayed with the current title text shown in the **Title** edit box (Fig. 5.9). The user may select and edit this text using the keyboard.

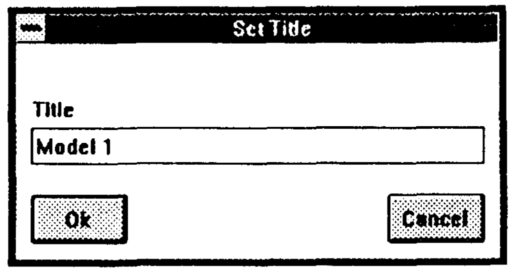


Figure 5.9

Choose the **Ok** button to use the contents of the **Title** edit box as the new model title and Main Window caption.

Choose the **Cancel** button to retain the existing model title and caption.

Settings : Depth mode

May be chosen at any time prior to performing the decompaction calculation. When **Depth mode** is selected, this option will be check marked (√) in the menu.

This selects the depth mode of operation for HotPot. In this mode, the data entered into the layer grids (see **File** menu, **Layer...**) are assumed to be depths to the bases of the layers. The decompaction calculation then computes layer thicknesses from these. A topographic surface *must* be defined before the decompaction calculation can be performed, as it is needed to compute the thickness of the topmost layer.

Settings : Isopach mode

May be chosen at any time prior to performing the decompaction calculation. When **Isopach mode** is selected, this option will be check marked (√) in the menu. **Isopach mode** is the default mode for HotPot.

This selects the isopach mode of operation for HotPot. In this mode, the data entered into the layer grids (see **File** menu, **Layer...**) are assumed to be thicknesses of the layers. A topographic surface need not be specified when working in isopach mode.

Settings : Area of Interest...

Must be chosen to define the area of interest prior to choosing any menu option which invokes data gridding. May be chosen at any time to show the current area of interest definition.

This will display a dialogue (Fig. 5.10) with edit boxes for entering the following information about the geographical area of interest:

North	the northern map limit
South	the southern map limit
N-S spacing	spacing between grid lines, north to south

West the western map limit

East the eastern map limit

W-E spacing spacing between grid lines, west to east

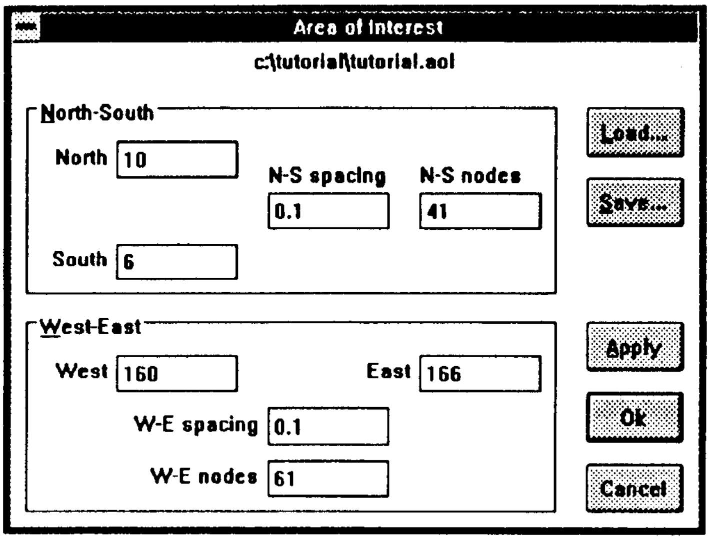


Figure 5.10

These data must be in appropriate and consistent map grid units, e.g. UTM metres, Latitude and Longitude degrees (see the note on co-ordinate systems in Appendix II.2.3). Decimal fractions are permitted.

Choosing the **Apply** button will cause HOTPOT to verify information entered into the dialogue edit boxes and to calculate and display the numbers of grid nodes in the N-S and W-E directions. This is particularly useful when defining a new area of interest. If there are too many grid nodes (maximum grid size is approximately 16129 nodes, i.e. 127 × 127 nodes), a warning message dialogue will be displayed; in this case, reduce the number of nodes by increasing the N-S and W-E spacing values and choose **Apply** again.

Choose the **Ok** button to complete the dialogue.

Choose the **Cancel** button to leave the dialogue contents unchanged.

The information entered into this dialogue may be saved for subsequent use by choosing the **Save...** button. Previously saved area of interest information may be reloaded by choosing the **Load...** button. Saved area of interest dialogue data is stored in an .aoi file. Both the **Load...** and **Save...** buttons will display file selector dialogues for *.aoi files.

Settings : Top Age...

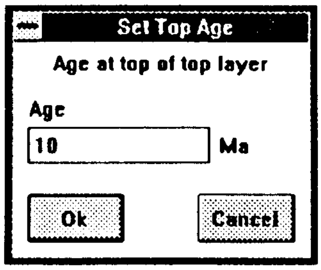


Figure 5.11

May be chosen at any time prior to performing the decompaction calculation.

A dialogue box is displayed with the current age of the top of the top layer shown in an edit box (Fig. 5.11). The user may select and edit this. The age of the top of the top layer is given in Ma (millions of years before present). The default value is zero, which is correct for basins where deposition is still in progress.

Choose the **Ok** button to use the new value.

Choose the **Cancel** button to retain the existing value.

Settings : Surface temperature...

May be chosen at any time after the decompaction calculation has been performed and an age button

Calculate

This is a drop-down menu with the following options:

Decompaction	perform decompaction calculation
Geothermal	perform geothermal calculation
Options...	select thermal conductivity *vs.* temperature relationship

Calculate : Decompaction

When using *isopach mode* this may be chosen at any time after a depth/density data table has been loaded and at least one layer has been added.

When using *depth mode* this may be chosen at any time after a depth/density data table has been loaded, at least one layer has been added and a topographic surface has been defined.

Choosing this option performs the decompaction calculation. During the calculation a Progress dialogue will be displayed. This reports the progress of the calculation, in terms of process, layer and percentage completed. The **Cancel** button on the Progress dialogue is not enabled.

Note: this calculation will be quite slow on a system which does not have a maths coprocessor installed.

When the decompaction calculation has been completed successfully, the HOTPOT Main Window display will be updated to show a series of stratigraphic columns which reflect the historical development of the basin. Each column will be headed by an *age button* (colour-coded yellow), representing an age boundary within the model, and will contain *layer buttons* (colour-coded cyan) for those layers which had been deposited at that time (Fig. 5.6). The boundaries between layer buttons are drawn in black to indicate a normal boundary and magenta to indicate an erosional boundary.

Calculate : Geothermal

May be chosen at any time after the decompaction calculation has been performed and thermal properties (surface temperature, heatflow and thermal conductivity) have been assigned to the model. If it is chosen prior to assigning thermal properties, message dialogues will warn the user and the calculation will not be carried out.

Choosing this option performs the geothermal calculation. During the calculation a Progress dialogue will be displayed. This reports the progress of the calculation, in terms of process, layer and percentage completed. The **Cancel** button in the progress dialogue is not enabled.

Note: this calculation will be quite slow on a system which does not have a maths coprocessor installed.

Calculate : Options...

May be chosen at any time.

Choosing this option opens a dialogue, Figure 5.15, which allows the user to define the thermal conductivity *vs.* temperature relationship. The complex nature of this relationship is discussed in Appendix I.3.

Data from the table are displayed as a set of curves on a depth *vs.* density scale in a Graph Display Window. This is an independent subsidiary window to the HOTPOT Main Window. (The manipulation of Graph Display Windows is described in section 5.5.) The window title will show the file name from which the table was loaded.

When this option is chosen after the decompaction calculation has been performed, depth/density curves for any proportional lithologies used, calculated during decompaction, will be shown.

Display : Depth/Conductivity

May be chosen at any time after a depth/thermal conductivity data table has been loaded.

Data from the table are displayed as a set of curves on a depth *vs.* thermal conductivity scale in a Graph Display Window. This is an independent subsidiary window to the HOTPOT Main Window. (The manipulation of Graph Display Windows is described in section 5.5.) The window title will show the file name from which the table was loaded.

When this option is chosen after the geothermal calculation has been performed, depth/thermal conductivity curves for any proportional lithologies used, calculated during geothermal modelling, will be shown.

Map displays: general information

The **Topography** option can only be chosen when a topographic surface has been defined (see **File** menu, **Topography...** option).

Before any of the other options can be chosen either an age button or a layer button must be selected in the HOTPOT Main Window. Only those map displays relevant to the model element corresponding to the selected button will be enabled in the menu.

The selected grid will be displayed in a Grid Display Window. This is an independent subsidiary window to the HOTPOT Main Window. (The manipulation of Grid Display Windows is described in section 5.6.) The window title will show the type of display, the age and, if appropriate, layer name.

Display : Topography

This is only useful when a digitised topographic surface is being used.

Display : Loaded thickness

May be chosen at any time after the decompaction calculation has been performed.

Display : Starved thickness

May be chosen at any time after the decompaction calculation has been performed.

Display : Bulk density

May be chosen at any time after the decompaction calculation has been performed.

Display : Layer thickness

May be chosen at any time after the decompaction calculation has been performed.

Display : Layer density

May be chosen at any time after the decompaction calculation has been performed.

Display : Heatflow

May be chosen at any time after a heatflow grid has been loaded.

Display : Layer conductivity

May be chosen at any time after a geothermal calculation has been performed in which the selected layer has been set to use depth-variable thermal conductivity.

Display : Layer temperature

May be chosen at any time after the geothermal calculation has been performed.

Help

This is a drop-down menu with the following options:

Memory usage...	provide information about memory usage
About HotPot...	information about the HOTPOT program

Help : Memory usage...

May be chosen at any time.

Choosing this option displays an information message box (Fig. 5.16) showing the current memory usage by the program. Values are given for Local Memory and Global Memory. Commonly used information in the model database is stored in Local Memory. Data grids are stored in Global Memory.

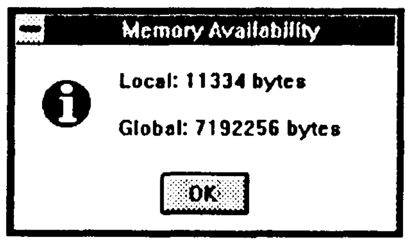


Figure 5.16

The amount of local memory available is not affected by the Windows operating mode. Local memory usage should not be excessive and should not cause problems.

The amount of global memory available is controlled by the Windows operating mode. In modes other than 386 Enhanced, Windows does not support virtual memory. This will restrict the size of model which can be processed in these modes, both in terms of number of layers and grid spacing within each layer. In 386 Enhanced mode virtual memory is available and there should be no problem with number of layers.

Choose the **Ok** button to acknowledge the information.

Help : About HotPot...

May be chosen at any time.

Choosing this option displays a dialogue giving the version number and other information about the version of HOTPOT being used. (This dialogue is automatically displayed when the program is started.)

Choose the **Ok** button to acknowledge the information.

5.5 The Graph Display Window

This type of window is used for displaying depth/density data, depth/thermal conductivity data and 1-D basin history displays, as in Figure 5.17.

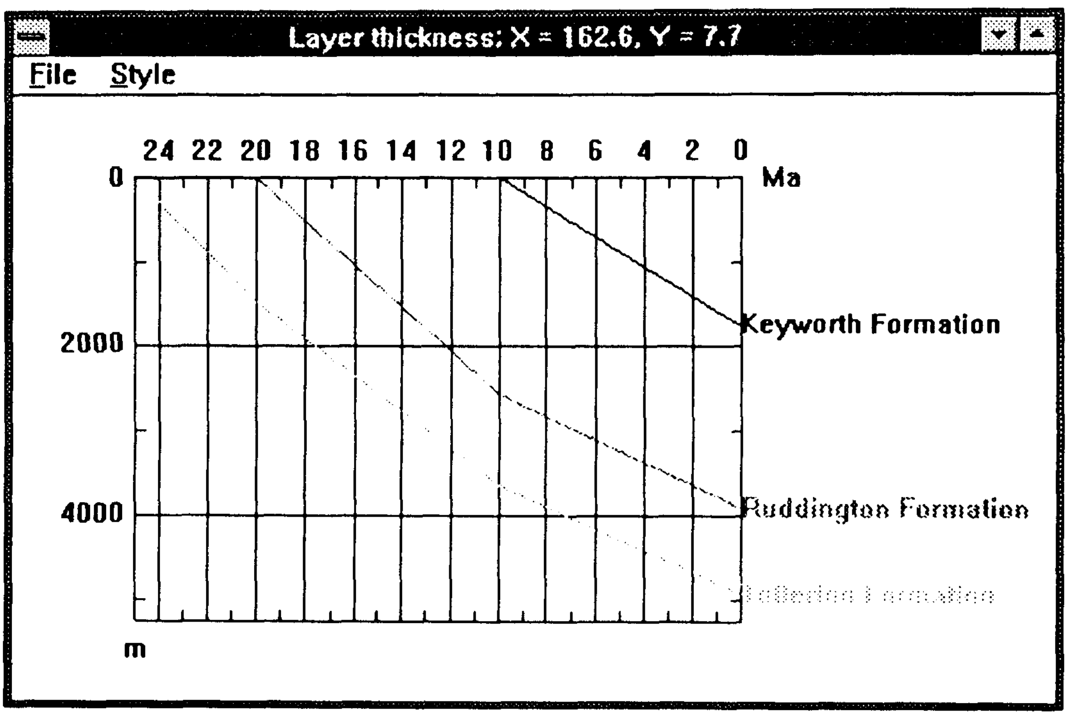


Figure 5.17

A Graph Display Window is sizeable and moveable and may be minimized or maximized. The graph displayed within the window may be zoomable or scrollable depending on the style setting. These windows are owned by the HOTPOT Main Window and will always appear on top of the HOTPOT Main Window. Any of these windows remaining open when either the **New** option is chosen from the HOTPOT Main Window **File** menu or the HOTPOT application is closed will automatically be closed. The user may close a Graph Display Window by double-clicking its system menu button.

An estimate of the value of a point on the displayed graph may be obtained by identifying the point with the cursor and clicking the left mouse button. The X and Y co-ordinates of the point will be displayed on the right of the menu bar, Figure 5.18. For depth/density and depth/thermal conductivity displays: X corresponds to density or thermal conductivity and Y to depth. For 1-D basin history displays: X corresponds to geologic age and Y to the type of data shown. Note that the value given is only an estimate due to the effects of screen resolution.

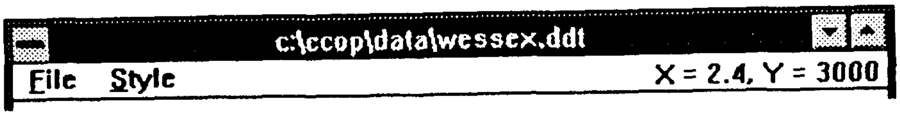


Figure 5.18

The menu bar contains the following items:

File	provides facilities for data output
Style	controls the window scroll/zoom system

File

This is a drop-down menu containing the following items:

Print	prints the displayed graph
Printer setup...	select or configure printer
Close	closes the graph display window

File : Print

Choosing this option causes the displayed data to be output to the selected printer via the Windows Print Manager. A Print dialogue box will be displayed during this process.

The representation of the graph on the printer depends on the selected printer and its configuration. These can be changed either by choosing the **Printer setup...** option from this **File** menu or by using the Windows Control Panel (described in Chapter 5 of the *Microsoft Windows User's Guide*). Most dot-matrix and laser printers will attempt some sort of grey-scale representation of colour.

File : Printer setup...

Choosing this option invokes a dialogue which allows printers to be selected and configured. (See description of Printer Setup dialogue under common dialogues, section 5.3.4.)

When a Windows 3 printer driver is in use, HOTPOT will, by default, print text reports using portrait page orientation and graphics using landscape page orientation. If the page orientation is changed by choosing **Printer setup...** from a HOTPOT Graph Display Window **File** menu, only the orientation of graphics will be changed.

File : Close

Choosing this option closes the graph display window and returns to the HOTPOT main window. The same effect can be achieved by double-clicking the graph display window system menu button (at the left end of the caption bar).

Style

This is a drop-down menu offering the following mutually exclusive options:

Zoomable	display zoomed to fit window
Scrollable	display scrolls within window

When the window is maximized, these styles yield identical displays. The selected style is check marked (√). Initially it is zoomable.

Style : Zoomable

When this style is chosen, the graph is zoomed to fit the window size. If the window size is changed, the graph size changes also. This is useful for making comparisons between entire graphs by displaying them side by side in separate windows.

Style : Scrollable

When this style is chosen, the window is shown with scroll bars at the bottom and the right side. The window shows a portion of the full size graph. The portion shown is selected by moving the scroll bar sliders with the mouse. The size of the portion is selected by sizing the window. This style of display is useful for comparing details of graphs by displaying them side by side in separate windows and scrolling the windows so the details to be compared are in view.

5.6 The Grid Display Window

This type of window is used for displaying data grids (thickness, temperature, etc.) as maps, Figure 5.19.

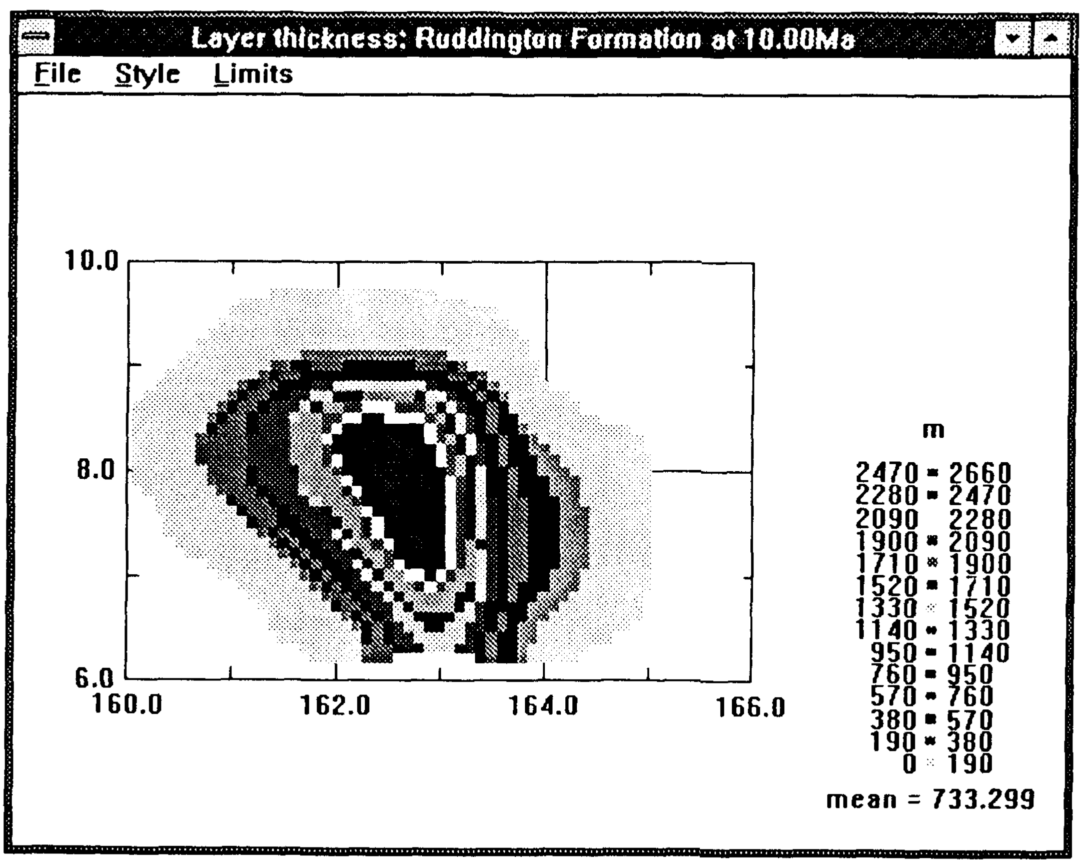


Figure 5.19

A Grid Display Window is sizeable and moveable and may be minimized or maximized. The map displayed within the window may be zoomable or scrollable depending on the style setting (it is initially zoomable). These windows are owned by the HOTPOT Main Window and will always appear on top of the HOTPOT Main Window. Any of these windows remaining open when either the **New** option is chosen from the HOTPOT main window **File** menu or the HOTPOT application is closed will automatically be closed. The user may close a Grid Display Window by double-clicking its system menu button.

The value of a node in the displayed grid may be obtained by identifying the node with the cursor and clicking the left mouse button. The map co-ordinates (X = easting or longitude and Y = northing or latitude) of the node and its data value (Z) will be displayed on the right of the menu bar, Figure 5.20. Unassigned nodes yield **Z = null**.

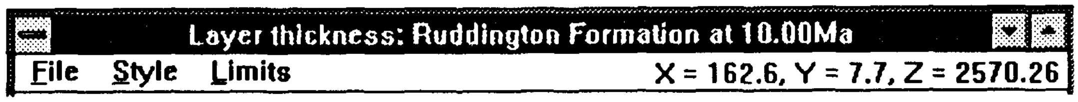


Figure 5.20

Grid nodes may be edited before the decompaction calculation is performed. The use of the grid node editor is described along with the Gridding Window in section 5.7.

After the decompaction calculation has been performed, 1-D basin history data can be extracted and displayed. Identify the node with the mouse-pointer and double-click the left mouse button. Data will be extracted from the corresponding nodes in all grids of the same type and displayed against a geologic time scale in a Graph Display Window; Figure 5.17, section 5.5 shows an example of this type of display.

The menu bar contains the following items:

File	provides facilities for data output
Style	select display style settings
Limits	define displayed data range and scale
Close	closes the grid display window

File

This is a drop-down menu with the following options:

Save...	save grid data in file
Print	print the displayed grid
Printer setup...	select or configure printer

File : Save...

Choosing **Save...** invokes a standard file selector dialogue. This will offer an automatically generated file name of .hpg type and will show a list of files of .hpg type in the current directory. The user may override the offered name by selecting from the file list or typing a new name. If no file type is specified, .hpg will be used.

The automatically generated name will be of the form:

hp*xxxxaa*.hpg

where: *xxxx* is the four hexadecimal-digit process identifier (PID) of the HOTPOT program in the current Windows session and *aa* is a pair of letters in the series **aa** (for the first file), **ab** (for the second) through to **zz**. Such automatically generated filenames are unique in any one directory. The maximum number of such files per directory per HOTPOT program run is 26^2 (676).

The data file created is ASCII text and may be transferred to other computer systems or programs. The format is described in Appendix II.4

File : Print

Choosing this option causes the displayed data to be output to the selected printer via the Windows Print Manager. A Print dialogue box will be displayed during this process.

The representation of the grid map on the printer depends on the selected printer and its configuration. These can be changed either by choosing the **Printer setup...** option from this **File** menu or by using the Windows Control Panel (described in Chapter 5 of the *Microsoft Windows User's Guide*). Most dot-matrix and laser printers will attempt some sort of grey-scale representation of colour (see **Style** menu, **Normal colours** and **Alternate colours** options).

File : Printer setup...

Choosing this option invokes a dialogue which allows printers to be selected and configured. (See description of Printer Setup dialogue under common dialogues, section 5.3.4.)

When a Windows 3 printer driver is in use, HOTPOT will, by default, print text reports using portrait page orientation and graphics using landscape page orientation. If the page orientation is changed by choosing **Printer setup...** from a HOTPOT Grid Display Window **File** menu, only the orientation of graphics will be changed.

File : Close

Choosing this option closes the grid display window and returns to the HOTPOT main window. The same effect can be achieved by double-clicking the grid display window system menu button (at the left end of the caption bar).

Style

This is a drop-down menu with the following options:

Small Crosses	grid cells shown as coloured small crosses
Large Crosses	grid cells shown as coloured large crosses
Filled Cells	grid cells shown as solid colour rectangles
Zoomable	display zoomed to fit window
Scrollable	display scrolls within window

Normal colours	colour scale for screen and colour printing
Alternate colours	colour scale for grey-scale printing
Annotate	overlay map with line-work

The **Small Crosses, Large Crosses** and **Filled Cells** styles are mutually exclusive. The selected style will be check marked (√). The initial style is **Filled Cells**. It is recommended that **Filled Cells** style be used for printing on dot-matrix, ink-jet, laser or similar printers. The crosses styles may be used for plotting on pen plotters.

Filled Cells	centred on the grid node and the same size as a grid cell.
Large Crosses	centred on the grid node and the same size as a grid cell.
Small Crosses	centred on the grid node and half the size of a grid cell.

The **Scrollable** and **Zoomable** options are mutually exclusive. The selected style will be check marked (√). The initial style is **Zoomable**. These options are identical to those described for the Graph Display Window. Refer to **Style : Zoomable** and **Style : Scrollable** under Graph Display Window, section 5.5.

If these style selections are changed, the current and any subsequent Grid Display Windows will use the new selections but any pre-existing windows will retain the old selections.

The **Normal colours** and **Alternate colours** styles are mutually exclusive. The selected style will be check marked (√). The initial style for each Grid Display Window is **Normal colours**. These style options apply to the current Grid Display Window only. The **Normal colours** style is for displaying grids on a colour screen or colour printer. The **Alternate colours** style is intended for displaying grids as smoothly gradational grey-scale images on monochrome printers (e.g. dot-matrix or laser printers).

Style : Annotate

May be chosen when a list of annotation files has been specified. The see under HOTPOT Main Window **File : Annotation...** (section 5.4) for a description of how to specify annotation files. The format of annotation files is described in Appendix II.3

Each time this option is chosen, the annotation selection state is switched between on and off. The on state is indicated by a checkmark (√) in the menu. The annotate style option applies to the current Grid Display Window only.

When annotate is on: Each time the grid data are displayed in the window or on the printer, the display will be overlaid by the digitised map line-work, read from the annotation files. This can slow the display considerably, especially if there are several annotation files and/or dense line-work.

Limits

This is a drop-down menu with the following mutually exclusive options:

Individual	scale set to this grid's limits
Group	scale set to limits of grid type group

User... scale set to user-supplied limits

Pseudo-maturity use 4-colour maturity scale

The selected option will be check marked. The initial limits setting is **Individual.** The **Pseudo-maturity** scale is only available for temperature grids.

Individual limits are determined from the minimum and maximum values present in the grid being displayed. They are useful for seeing detail in the variations in the data.

Group limits are determined from the minimum and maximum values present in all grids in the same display group (e.g. all the temperature grids, all the layer thickness grids, etc.). They are useful for comparing grids, e.g. the thicknesses of a layer at different stages of decompaction.

When the **User...** limits option is chosen, a dialogue is opened showing the current minimum and maximum value settings in edit boxes (Fig. 5.21). Edit these to the values required then choose the **Ok** button to display the data using the new limits. Choose the **Cancel** button to retain the existing limits. The User limits option is useful for emphasising features in the displayed data. Note that any data values falling outside the user limits (i.e. below minimum or above maximum) will be shown in the minimum and maximum colour bands.

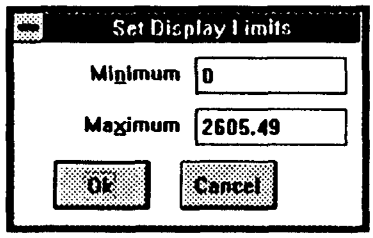


Figure 5.21

The **Pseudo-maturity** scale shows four colour bands, representing: under-mature zone, oil generating zone, gas generating zone and over mature zone. The boundaries are determined solely from temperature (i.e. a TTI-type calculation is not used). The boundary temperatures are shown, in °C. Note that this display does not take into account any higher temperatures that may have existed earlier in the basin history. To obtain a true picture of the basin maturity, the user must examine and compare pseudo-maturity scale temperature plots for all layers at all ages in the model. The cover illustration of this report shows an example of a pseudo-maturity display.

If the limits selection is changed, the current and any subsequent grid display windows will use the new selection but any pre-existing windows will retain the old selection. If the **Pseudo-maturity** option is selected when a non-temperature grid is displayed, the **Individual** option will be used instead.

5.7 The Gridding Window

This is a special type of Grid Display Window which is used during the data gridding process.

Only one Gridding Window can be open. When it is in use all menu options which involve data gridding are disabled. It is opened during the processing of the **Layer...**, **Heatflow...** and **Topography...** options in the HOTPOT Main Window **Files** menu. It is initially displayed as a full screen window and, although it may be resized by the user, it is recommended that it be used full-size.

Unlike a Grid Display Window, the Gridding Window has no **Limits** item in its menu bar, no **Close** option in its **File** menu and it cannot be closed by double-clicking the system menu button in the top-left corner.

When the Gridding Window is opened (Fig. 5.22), it has an empty map graticule showing the area of interest. There are three buttons: **Accept, Grid...** and **Cancel**. The **Accept** button is initially disabled; it is only enabled when a valid grid has been generated.

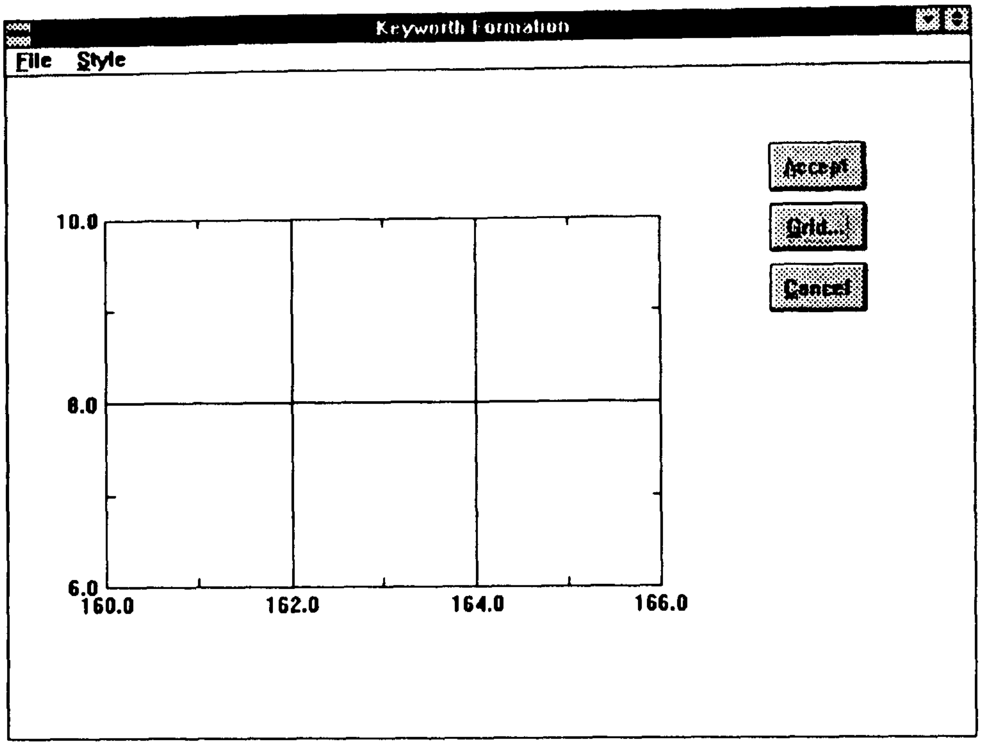


Figure 5.22

The **Accept, Grid...** and **Cancel** buttons may be chosen by using the keyboard as well as by using the mouse. The TAB and BACKTAB (i.e. SHIFT + TAB) keys move the focus by one button at each press. The SPACEBAR is pressed to choose the button which has the focus. Alternatively, a button may be chosen by pressing its initial letter key, e.g. A for **Accept**. Additionally, **Cancel** may be chosen by pressing the ESC key. The provision of keyboard control allows the Windows Recorder program to be used more effectively to record and replay HOTPOT sessions, e.g. for demonstrations or presentations.

Choosing the **Cancel** button cancels the command which initiated the gridding process, closes the Gridding Window and returns control to the HOTPOT Main Window.

Choosing the **Grid...** button opens a dialogue which shows the current value of the search radius (Figure 5.23). Edit the value to that required then choose the **Ok** button to start the gridding process. The **Cancel** button may be chosen to cancel the dialogue and return to the Gridding Window.

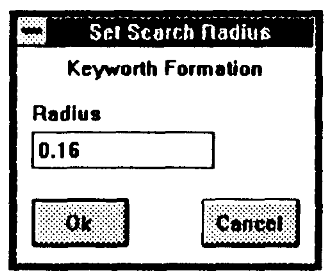


Figure 5.23

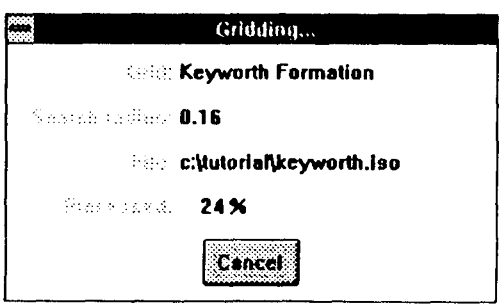


Figure 5.24

During the gridding process a Progress dialogue will be shown (Figure 5.24). This tells the user which data file is open and the percentage of the file processed. *Note: this calculation will be quite slow on a system which does not have a maths coprocessor installed.* If the user realises something is wrong, e.g. the search radius is incorrect, then the **Cancel** button in the Progress dialogue should be chosen to cancel the gridding process and return to the Gridding Window.

When the gridding process has been completed successfully, the grid will be displayed on the map

graticule and the **Accept** button will be enabled.

If the grid is satisfactory, choose the **Accept** button to complete the gridding operation, close the gridding window and return to the HOTPOT main window.

If the grid is not satisfactory, choose the **Grid...** button to repeat the gridding process with a different search radius.

The search radius and grid acceptability are discussed in Appendix III.

The grid node edit function is always available in the Gridding Window. To use it: identify the grid-node with the cursor and double-click the left mouse button. The **Edit Grid Node** dialogue (Figure 5.25) will be displayed. This will show the selected grid-node map co-ordinates as a subtitle and the value of the grid-node in the edit box. The value may then be selected and edited using the keyboard. Unassigned (null) nodes have their value shown by the key-word "null"; nodes can be set to null by entering this key-word.

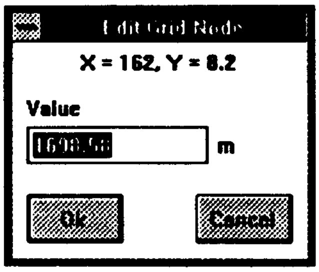


Figure 5.25

Choose the **Ok** button to insert the edited value into the grid.

Choose the **Cancel** button to leave the existing value unchanged.

The **File** drop-down menu has an additional item in the Gridding Window:

Load...	retrieve data from a saved grid file

File : Load...

Choosing this option allows a grid saved from the Gridding Window to be reloaded into the Gridding Window. This avoids the need to regrid isopach data when repeating modelling sessions. It is particularly useful when the preparation of a grid involves time-consuming manual editing of grid nodes. This function may also be used to load data gridded using other software, such as mapping and contouring programs (grid file format conversion will probably be required; Appendix II.4 describes the HOTPOT grid file format).

Load... invokes a standard file selector dialogue which will, by default, search for files of .hpg type. The grid title from the selected file will be displayed in a confirmation message box along with the title for the required grid, Figure 5.25.

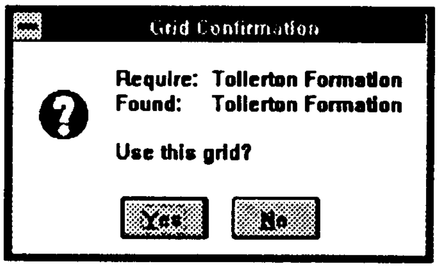


Figure 5.25

Choose the **Yes** button to load the grid into the Gridding Window.

Choose the **No** button to return to the Gridding Window without loading the grid.

The grid loading operation will verify the area-of-interest specification stored in the file against the area-of-interest required; if they do not match, a warning message dialogue will appear and the grid will not be loaded.

The **Accept** button in the Gridding Window will only be enabled if the grid is loaded successfully.

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Glossary of selected terms

Algorithm	A structured method of solving a problem, forming the basis of a computer program.
Anti-masking contours	Extra contours positioned around a data set, to prevent the gridding procedure assigning null nodes and thus to control masking operations on other grids. Their use is illustrated in the Tutorial, see sections 4.1.1 and 4.3.5. (See also: Masking)
Backstripping	Reconstruction of the subsidence history of a point location by the sequential removal of successively older stratigraphical layers. As each layer is removed, the remaining layers are allowed to decompact according to some appropriate function.
Button	A box in a dialogue or window which may be chosen or selected.
Caption bar	The strip displayed along the top edge of the window containing title text. Shown highlighted (traditionally in blue) when the window is active.
CCOP	Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas; Technical Secretariat based in Bangkok, Thailand.
Cenozoic	The division of geological time extending from about 65 million years ago to the present day.
Check box	A square box in a dialogue which is marked with a × symbol when it is selected. It is used to enable a program option.
Checkmark	A √ symbol, used in a menu to indicate either a currently selected option or to provide visual confirmation that a procedure has been carried out.
Choose	To pick an item that begins an action within Microsoft Windows. How this is done depends on the type of item and the method used. (Cf. Select)
Click	To press and release a mouse button.
Combo-box	Synonym for drop-down list box.
Control contours	Extra contours interpolated between existing, widely-spaced contours in order to prevent the gridding procedure assigning null nodes in areas of continuous data cover. Their use is illustrated in the Tutorial, see sections 4.1.1 and 4.3.5. See also Appendix III.
Decompaction	Calculating the original thickness of a layer prior to its burial and compaction by younger overlying layers. (See also Backstripping.)
Depth contour	Synonym for structure contour.
Dialogue	A specialised window which is used both to provide information to and request information from the user of a program, with reference to a particular program procedure.

Double-click	To press and release a mouse button twice, in quick succession, without moving the mouse.
Drop-down list box	A type of list box which normally shows only the selected item. The list of alternatives is obtained by choosing the button at the right of the box.
Edit box	A box in a dialogue in which text may be entered and/or edited by the user.
Grid	System of regularly spaced observations (or calculations) over a mapped area.
Grid-node	A intersection between a N-S grid line and an E-W grid line of a map graticule, at which a parameter (e.g. thickness, temperature, etc.) is observed or calculated.
Gridding	The computation of a grid from scattered data.
Hardware	The computer and its associated peripheral equipment (display screen, printer, etc.).
Heatflow	The rate at which heat is lost from the crust of the earth to the atmosphere. Units: mW m^{-2}
Hotpot	A traditional English dish of vegetables and, optionally, meat. The ingredients are placed in layers in a basin and then cooked.
Isopach	A line joining points of equal layer thickness.
Isotherm	A line joining points of equal temperature.
List box	A box in a dialogue listing choices (e.g. file names). If there are many choices, the list box may have a scroll bar on its right side.
Lithology	Rock type or composition.
Ma	Millions of years before the present.
Masking	A grid-to-grid operation in which the values set in one grid are used to control the assignment or interpretation of values in a second grid. HOTPOT uses two types of grid masking: 1) during modelling calculations, values in a layer grid are set null where values in the corresponding grid for the layer above are null; 2) in displays, density and temperature grid values are not shown where the corresponding thickness grid values are zero.
Maturity	Measure of thermal alteration of organic matter in rocks indicative of their hydrocarbon generating potential; thus rocks can be classified as undermature, mature for oil, mature for gas, or overmature according to the degree of alteration of their organic matter.
Menu	A list of program commands or options.
Menu bar	A list of menu names displayed along the top of a window.
Microsoft Windows	A Graphical User Interface for IBM-PC type computers in which data, programs etc. are represented by stylised images on the computer display

	screen and manipulated by a user-operated cursor. (Trademark of Microsoft Inc.)
ODA	United Kingdom Overseas Development Administration.
Option button	A round button in a Windows dialogue which is marked with a • symbol when it is selected. Option buttons are grouped and only one from a group of may be selected.
Overpressure	A situation commonly met in sedimentary basins where pressure of pore fluids in rocks is greater than would be normally expected.
Palaeo-	Prefix meaning 'ancient' or 'of past times' (from Greek); e.g. palaeotemperatures – temperatures in the past.
Pseudo-maturity	A HOTPOT display which presents present day temperature or palaeotemperature maps as organic maturity estimates.
Radio button	Synonym for option button.
Scattered data	Irregularly spaced observations over a mapped area.
Scroll bars	Strips drawn at the bottom and/or right of a window when the data display size is larger than the window size. They are used to select the portion of the data display to be shown in the window.
Sedimentary basin	A depression in the earth's surface resulting from crustal subsidence and infilled by rocks formed largely by sedimentary processes.
Select	To mark an item for use in a subsequent Microsoft Windows action. (Cf. Choose)
Software	A computer program or programs. (Cf. Hardware)
Stratigraphy	The study of stratified rocks, especially their sequence, composition and correlation.
Structure contour	A line joining points on the base of a stratigraphic unit that are of equal depth below a standard datum, typically mean sea level (MSL).
Text box	Synonym for edit box.
Thermal conductivity	A measure of the ability of rocks to conduct heat. Units: mW m^{-1} °K^{-1}
WGRA	CCOP Working Group on Resources Assessment.
Window	A rectangular area on a computer display screen which is used by a program to communicate with its user.

APPENDIX I

Auxiliary data

I.1 Depth – Density data

The standard depth-density compaction curves provided with HOTPOT are illustrated in Figure I.1 and stored in file malay.ddt. The curves are based upon a detailed study of depth-density data from Cenozoic sedimentary sequences in SE Asia. The curves were further constrained at shallow (<500m) and great (>3500m) depths by published information (Sclater & Christie 1980; Baldwin & Butler 1985).

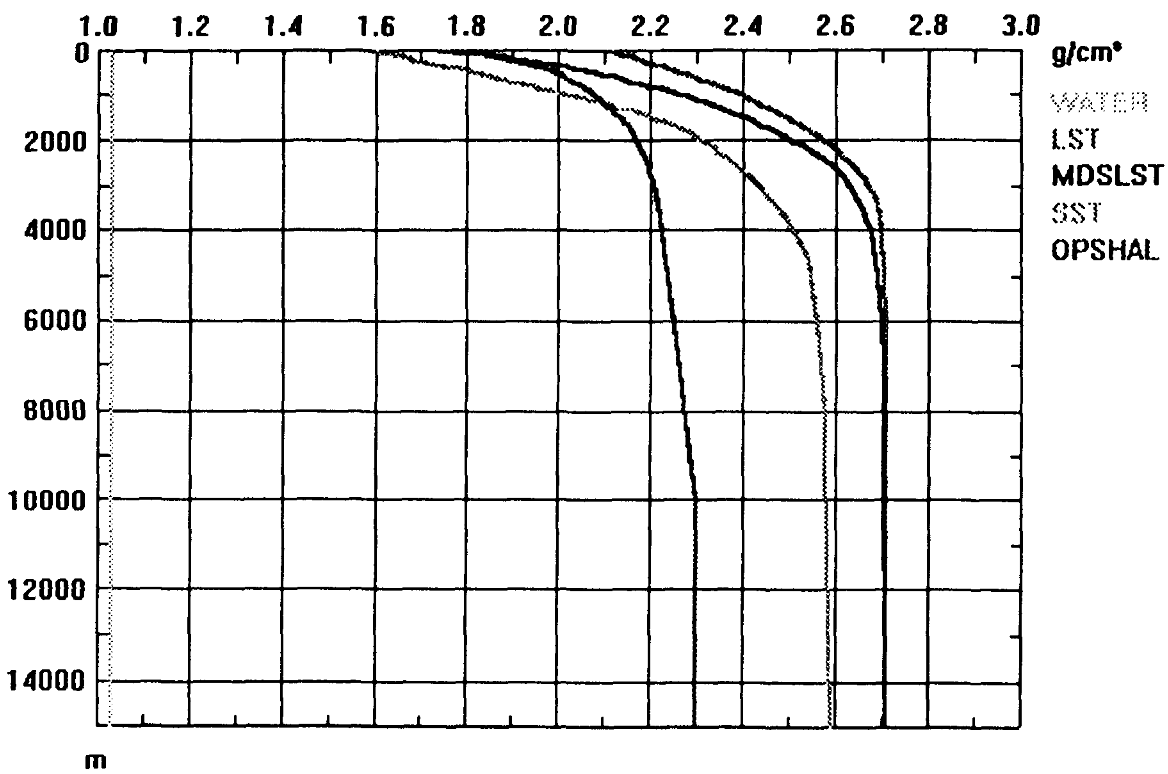

Figure I.1

I.2 Depth – Thermal conductivity data

The standard depth-thermal conductivity curves provided with HOTPOT are illustrated in Figure I.2 and stored in file malay.dkt. The curves are based upon data from Cenozoic sedimentary sequences in SE Asia, with further constraints from published information (Issler & Beaumont 1989; Sclater & Christie 1980).

An alternative set of curves are supplied in the file danish.dkt (Fig. I.3). These are based on data from the continental shelf under the Danish sector of the North Sea (Balling *et al.* 1980), except for overpressured shale, which is taken from the SE Asian data.

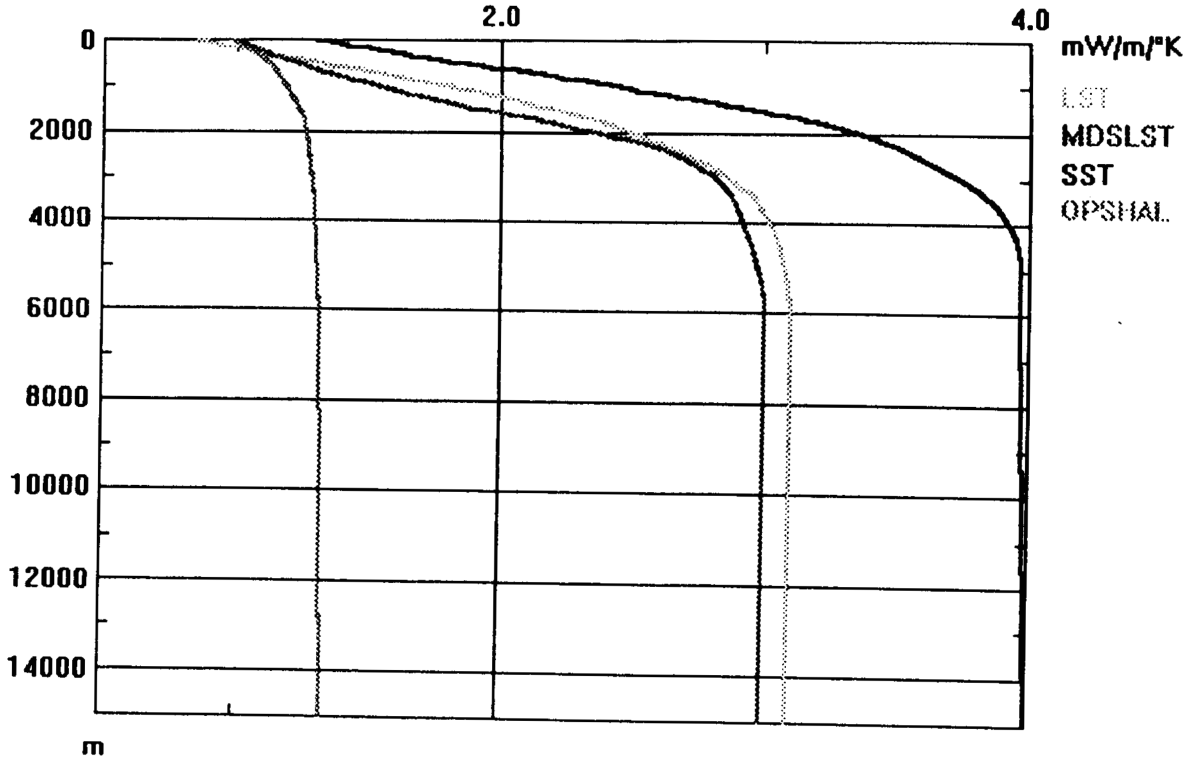

Figure I.2

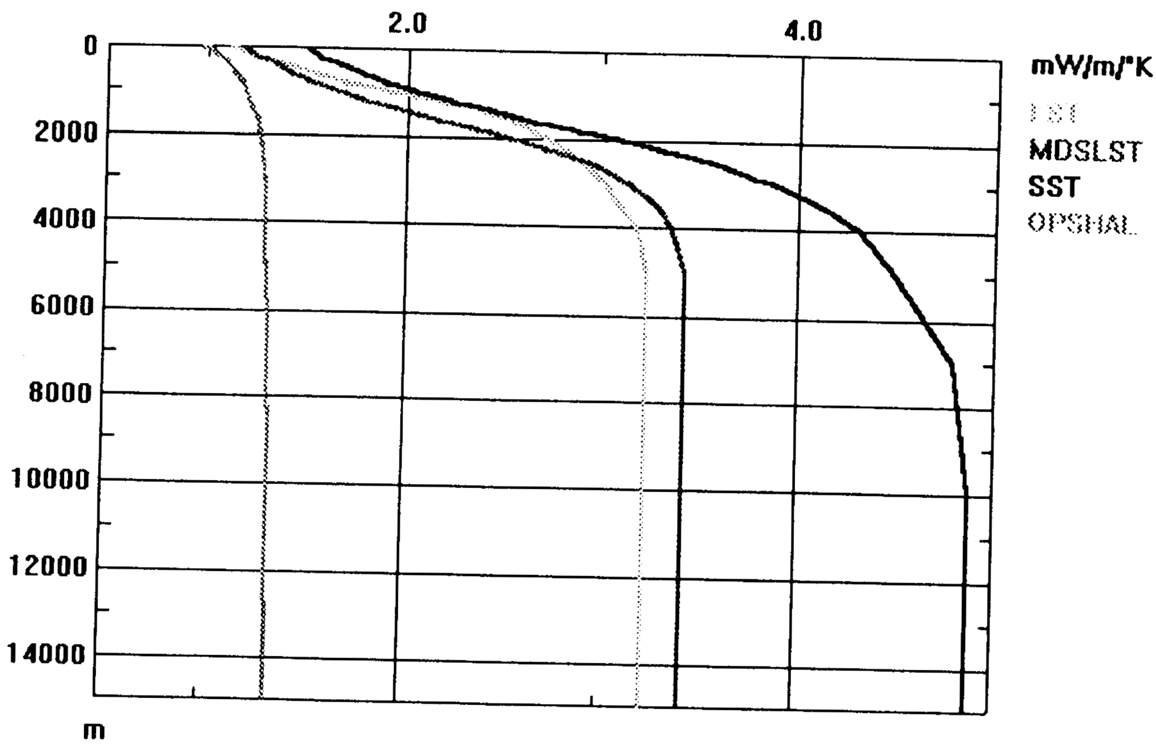

Figure I.3

I.3 Thermal conductivity – Temperature relationship

It is necessary to take into account the effects of temperature on thermal conductivity. The precise nature of this relationship is not well described, but basically, for a given rock type, thermal conductivity decreases with increasing temperature (see e.g. Houbolt & Wells 1980; Wan Ismail 1984; Cermak & Bodri 1986).

HOTPOT provides four options for specifying the thermal conductivity – temperature relationship; these are described in the following sub-sections. The required option is selected by choosing the Options... item from the Calculate drop-down menu of the HOTPOT main window (see section 5.4). The Cermak & Bodri (1986) option is automatically selected when the program is started.

Cermak & Bodri (1986)

$$k_T = \frac{k_{20}}{(1 + 0.001\Delta T)} \quad \text{for } T \leq 300\ °\text{C}$$

$$k_T = k_{300} \qquad \text{for } T > 300\ °\text{C}$$

where: ΔT = T - 20 °C

T = temperature, °C

k_T = thermal conductivity at temperature T

k_{20} = thermal conductivity at 20°C

k_{300} = thermal conductivity at 300°C

Sekiguchi (1984)

$$k_T = 366(k_{20} - 1.84)\left(\frac{1}{(T+273)} - 0.00068\right) + 1.84 \qquad \text{for } T \leq 300\ °\text{C}$$

$$k_T = k_{300} \qquad \text{for } T > 300\ °\text{C}$$

Somerton (1992)

$$k_T = k_{20} - 0.001\Delta T\,(k_{20} - 1.38)\left(k_{20}[0.0018(T+273)]^{-k_{20}/4} + 1.28\right)k_{20}^{-0.64} \quad \text{for } T \leq 300\ °\text{C}$$

$$k_T = k_{300} \qquad \text{for } T > 300\ °\text{C}$$

None

With this option selected, the thermal conductivity – temperature relationship is disabled and thermal conductivity remains constant. The results obtained will be unrealistic but provide a useful benchmark to assess the effects of the other options.

The three thermal conductivity – temperature relationship options have a 300 °C automatic cut-off. This is because radiative heat transfer becomes important above about 300 °C, with a consequent (and poorly understood) increase in effective thermal conductivity. We strongly recommend that this cut-off is retained. The HotPot geothermal calculation options dialogue provides a facility to override the cut-off or modify the cut-off temperature.

Figure I.4 illustrates the three thermal conductivity – temperature relationships, showing how initial thermal conductivities (k_{20}) of 1.0 to 6.0 mW m^{-1} $°K^{-1}$ vary over the temperature range 20 to 400 °C with no cut-off temperature. Figure I.5 shows these data with the 300 °C cut-off.

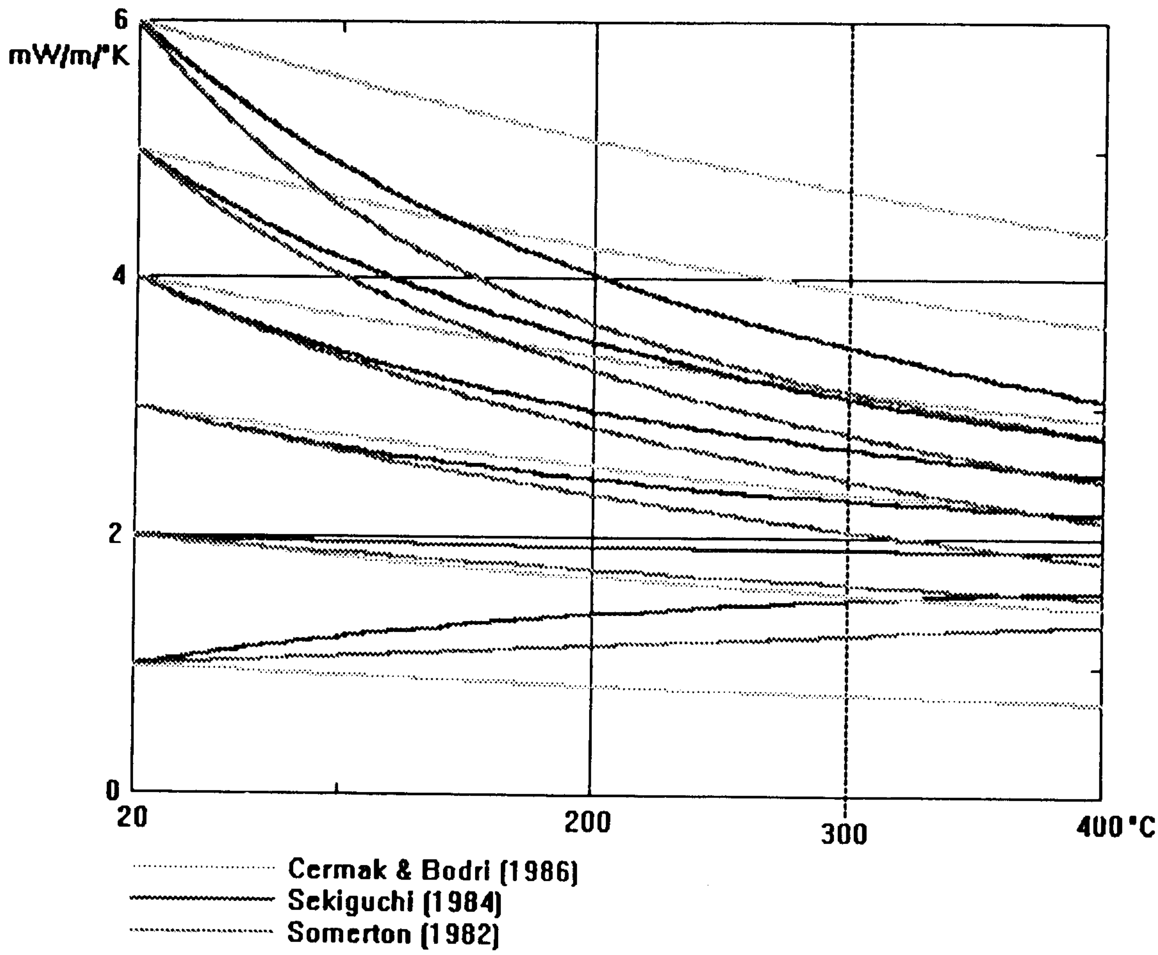

Figure I.4

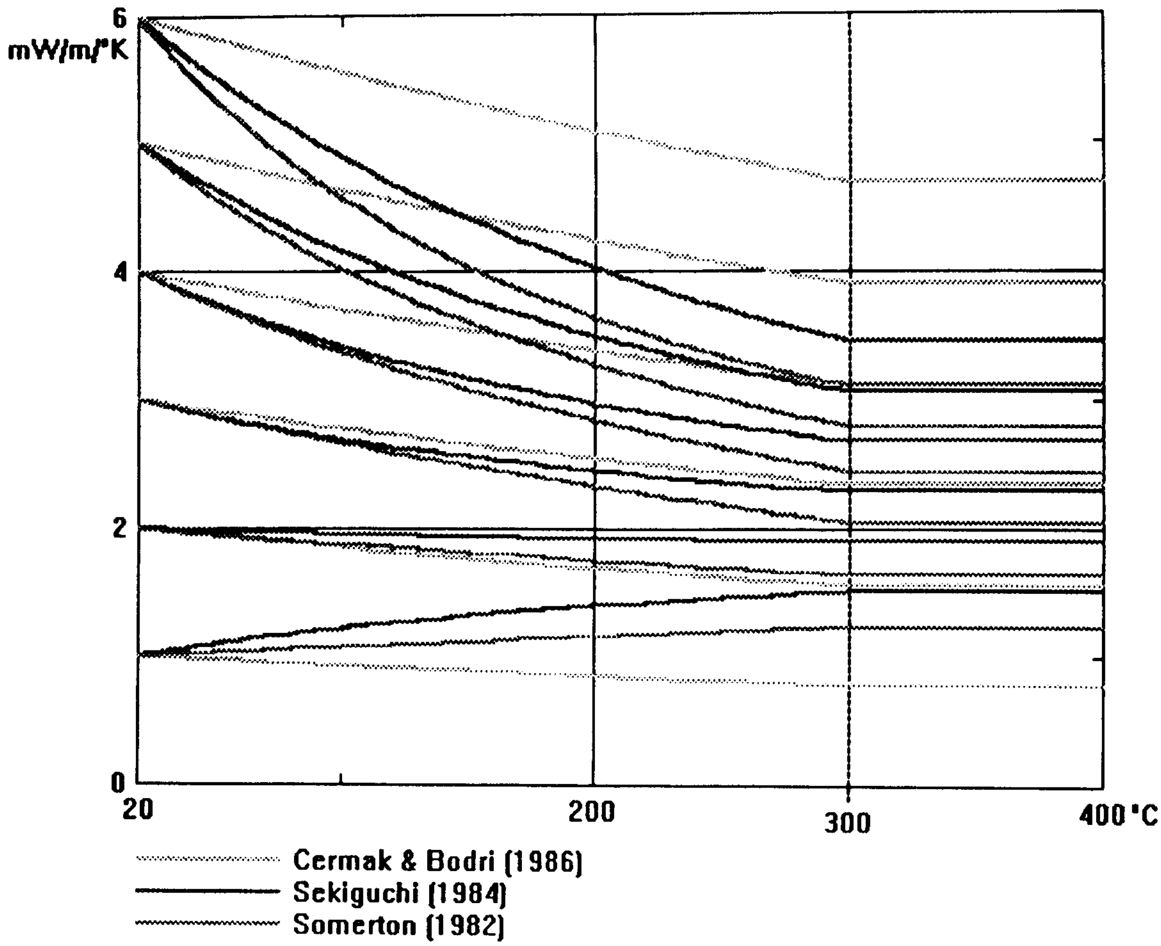
6
mW/m/°K
4
2
0
20
200
300
400 °C
Cermak & Bodri (1986)
Sekiguchi (1984)
Somerton (1982)

Figure I.5

APPENDIX II

HOTPOT data file formats

General

The HOTPOT program uses several types of data file:

1. depth-data table files
2. digitised contour files
3. annotation files
4. grid data save files

All these files are ASCII text format. Therefore, they can be manipulated using standard text editors (e.g. Windows Notepad) or word processors (e.g. Windows Write) in non-document mode. They can also be printed out. This appendix describes the format of these file types in order that users can prepare their own data for use with the program.

II.1 Depth-data table files

The depth-data table file format is used for storing digitised depth/density curves and digitised depth/thermal conductivity curves. A depth-data table is simply a list of depth values and corresponding observed data measurements for a specific lithology. Several such tables may be incorporated into one file. The recommended file types are .DDT for depth/density data and .DKT for depth/thermal conductivity data.

To illustrate the format, here are some extracts from a depth/density table file for use with the HOTPOT package:

```
! malay.ddt - density/depth table for decompaction program
!               based on well data from the Malay Basin

Water sea water
0    1.03

Lst limestone
0.000 2.114
54.170 2.133
146.103 2.162
...       ...
...       ...
10000.00 2.710
15000.00 2.710

MdSlst mudstone/siltstone
0.000 1.743
26.273 1.773
...     ...
...     ...
```

All blank lines in the file are ignored; their use is recommended to improve readability of the file.

All text on a line to the right of an exclamation point, !, or a hash, #, is treated as comment and ignored. The use of comments is recommended as *aides memoire* to the data contained in the file (e.g. its source and purpose).

Each table within the file begins with a header line. This comprises a one-word lithology code followed by one or more SPACE and/or TAB characters and then a description of the lithology. For example: in the second header in the extract, the lithology code is `LSt` and the description is `limestone`.

Following the header line are one or more records each containing a pair of values. The first value is the depth, in metres below sea-level, and the second value is the corresponding density, in grams per cubic centimetre. The depths do not have to be in regular increments; neither do they have to be in order. The values are read in free-format.

The end of a table is marked by either the header line for the next table or the end-of-file.

As a special case, sea water is treated as a lithology whose density does not vary with depth. The depth-density table for sea water is:

```
Water sea water
0    1.03
```

Other lithologies with effectively constant density, such as anhydrite or salt, may be defined in a similar manner.

II.2 Digitised contour files

Digitised contour map data used with HOTPOT may include:

- isopachs digitised from time-slice isopach maps
- depth contours digitised from depth maps
- topographic or bathymetric contours digitised from geodetic or hydrographic maps
- heatflow contours digitised from heatflow maps

HOTPOT will automatically recognise several file formats for this type of data:

- the digitised isoline format used by many British Geological Survey computer programs
- the geographic data format used for maps produced by the CCOP WGRA Phases I and II
- formats used by several commercial mapping programs used by CCOP Member Countries

These formats are recognised by analysing the contents of a file rather than by making assumptions based on a file type suffix. This means that HOTPOT will correctly interpret other file formats which are similar to the ones it has been programmed to recognise.

II.2.1 BGS isoline file format

The standard file type is .ISO. HOTPOT initially assumes this file format and file type when it asks the user to specify a list of digitised contour files.

To illustrate the format, here are some fragments of a .ISO file:

```
# an example of a digitised contour file
!C 0
99.791 11.539 0
99.790 11.565 0
99.789 11.591 0
...    ...
...    ...
101.352 12.056 0
101.378 12.048 0
101.403 12.045 0
101.428 12.044 0
101.440 12.043 9
!C 500
99.994 11.646 0
99.999 11.672 0
100.010 11.701 0
100.018 11.727 0
100.027 11.754 0
```

All blank lines in the file are ignored; their use is recommended to improve readability of the file.

All text on a line to the right of an exclamation point, `!`, or a hash, `#`, is treated as comment and ignored. The use of comments is recommended as *aides memoire* to the data contained in the file (e.g. its source and purpose).

The first line is a *contour value record*. This begins with the pseudo-comment `!C`. The contour value then follows on the same line.

For example: in the extract, the first contour value record is `!C 0` which indicates the start of the 0 (zero) contour, and the second is `!C 500` which indicates the start of the 500 contour.

Following each contour value record are two or more records each containing three values. The first value is the X co-ordinate (map easting or longitude), the second is the Y co-ordinate (map northing or latitude) and the last is the flag number. The values are read in free-format. Each such record represents a digitised point on the contour. The last point on the contour conventionally has the flag number `9`, although this is not strictly necessary as the HOTPOT program does not use the flag number but recognises the end of a digitised contour by either encountering a new contour value record or the end-of-file.

II.2.2 Alternative contour file formats

HOTPOT interprets a digitised contour file according to the following rules:

- a line in a file containing a single numeric value is recognised as a contour value record
- subsequent lines in the file containing two (or more) numeric values are treated as digitised points along that contour, the first value being regarded as the X co-ordinate and the second as the Y co-ordinate
- a contour is terminated when either a new contour value record or the end-of-file is found
- non-numeric data in the file are ignored.

This allows several digitised contour file formats to be recognised and interpreted correctly.

The CCOP WGRA digitised contour format

This format was devised for digitising the total sediment thickness and time-slice isopach maps produced by CCOP Member Countries during the Phase I and II projects of the WGRA programme. It should also be compatible with the line file format used by ARC/INFO (but note that ARC/INFO line attributes may need translating to contour values, depending upon how the line attributes have been encoded). The normal file type is .GEO. The format is illustrated by the following extract from a .GEO file:

```
0
99.8586 11.8245
99.9018 11.8848
99.9487 11.9316
99.9877 11.9592
100.0000 11.9639
END
1
100.0000 10.4530
99.9823 10.4431
END
2
99.8361 11.4528
99.8905 11.3737
99.8961 11.3675
END
```

Each segment of digitised contour begins with a contour value on a line by itself. This is followed by one or more lines, each with two values representing the X, Y co-ordinates of a digitised point on the contour. A line containing the keyword END terminates the segment. The contour values are specified in kilometres for isopachs. The example shows segments of the 0km, 1km and 2km contours.

ZCAP format

This data format is produced from the Zycor ZCAP digitising software. The format is illustrated by the following extract from a data file:

```
0.1E+31 2000
106.116 48.033
105.776 48.270
105.268 48.355
104.840 48.679
104.443 49.334
104.291 49.906
104.206 50.445
104.138 50.873
0.1E+31 3000
108.278 49.809
108.060 49.897
107.953 50.323
108.271 50.975
```

Each line comprises two numeric values. If the first value is 0.1E+31 (i.e. 0.1×10^{31}) then the second value is interpreted as a contour value. Otherwise, the first value is the X co-ordinate and the second the Y co-ordinate of a digitised point on that contour.

II.2.3 Co-ordinate systems

The X and Y co-ordinates may be either map easting and northing or longitude and latitude. Their

units are immaterial (use kilometres, metres or degrees as appropriate) but must be consistent with the units used to specify the area of interest. HOTPOT assumes the use of a regular Cartesian co-ordinate system, i.e. X co-ordinates increase from west to east and Y co-ordinates increase from south to north. Where longitude and latitude are used, the origin is the intersection of the Greenwich Meridian (0° longitude) with the Equator (0° latitude); longitudes west of the Greenwich Meridian and latitudes south of the Equator are indicated by negative numbers.

II.3 Annotation files

These files are used to store digitised line-work which is to be plotted as overlays on displayed maps, e.g. coastlines. The recommended file type is .DAT.

To illustrate the format, here is an example of an annotation file:

```
! an example of a digitised annotation file, part of
! COAST.DAT from the Tutorial data set

160.007 8.086 0
160.058 8.114 0
160.096 8.164 0
160.135 8.214 0
...     ...
...     ...
161.132 9.981 0
161.144 9.999 9
161.692 10.000 0
161.729 9.946 0
...     ...
...     ...
```

All blank lines in the file are ignored; their use is recommended to improve readability of the file.

All text on a line to the right of an exclamation point, `!`, or a hash, `#`, is treated as comment and ignored. The use of comments is recommended as *aides memoire* to the data contained in the file (e.g. its source and purpose).

The file contains two or more records each comprising three numeric values. The first value is the X co-ordinate (map easting or longitude), the second is the Y co-ordinate (map northing or latitude) and the last is the flag number. The values are read in free-format. Each record represents a digitised point on an annotation line. The last point on a line has the flag number `9`. The example fragment of an annotation file shown above contains two lines. The first ends at X = 161.144, Y = 9.999 and the second starts at X = 161.692, Y = 10.000. The notes on co-ordinate systems given in II.2.3, above, apply here also.

Normally, line work from annotation files is drawn in black at the standard line thickness. However, the flag numbers may be used to select other colours from the standard Windows colour palette and to change the line thickness. The colour and thickness selection is set by the flag number of the first point on the line; the example file could be edited to:

```
! part of COAST.DAT from the Tutorial data set
! modified to use different line colours and thicknesses

160.007 8.086 214    ! first line: thickness 2, colour 14
160.058 8.114 0
160.096 8.164 0
160.135 8.214 0
...     ...
...     ...
161.132 9.981 0
161.144 9.999 9      ! end of first line
```

```
161.692 10.000 107   ! second line: thickness 1, colour 7
161.729 9.946 0
...     ...
...     ...
```

The thickness number is a multiplier for the standard line thickness, therefore thickness 1 is the same as the standard line thickness, thickness 2 is twice the standard line thickness and so on.

The basic Windows colour palette contains 20 values. HOTPOT sets the first 16 of these to:

0	black	8	dark grey
1	dark red	9	light red
2	dark green	10	light green
3	dark yellow	11	light yellow
4	dark blue	12	light blue
5	dark magenta	13	light magenta
6	dark cyan	14	light cyan
7	light grey	15	white

Any other entries in the colour palette will depend on factors outside the control of the HOTPOT program and are, therefore, unlikely to be consistent.

II.4 Grid data save files

To illustrate the format, here is an example grid data file, for the small (4 rows × 4 columns = 16 nodes) grid shown in Figure II.1.

```
Globals...
Titles...
Example Grid
Grid...
cols = 4
rows = 4
Xmin = 1000
Xmax = 4000
Ymin = 6000
Ymax = 9000
Zmin = 2.25
Zmax = 3.5
Znull = -9999
2.25
2.625
3.125
3.5
2.42
2.5
2.875
3.375
2.58
2.67
2.75
3.125
2.75
2.83
2.92
3
End
```

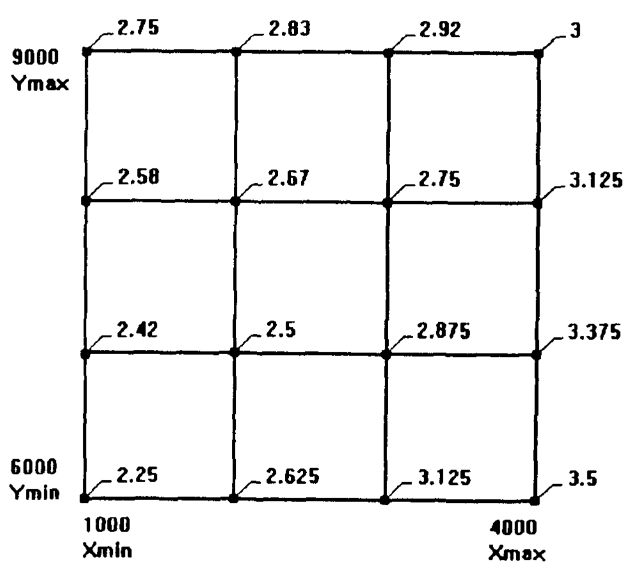

Figure II.1

These files are used to store grid data extracted from HOTPOT by selecting the **Save...** option from either the Gridding Window or a Grid Display Window **File** menu. The data from such a file may be read into a HOTPOT grid by selecting the **Load...** option from the Gridding Window **File** menu.

The files may also be read by other computer programs, such as data visualisation packages. Grid data produced by other computer programs, such as mapping and contouring packages, may be translated to this format and then loaded directly into HOTPOT grids. The recommended file type is .HPG.

This file format has proved useful in a number of British Geological Survey computing applications that use gridded data. The format includes features needed for some of these other applications and, therefore, not all parts of it are used by the current version of HOTPOT. To allow flexibility and compatibility, the format is divided into named sections. Programs writing data need only write the sections their target applications will want to read. Programs reading data need only search for and then read the sections they require. As a safeguard, a program to read this file format *must* be coded so that it will detect when a section that it requires is wholly or partly missing and take appropriate action (e.g. issue a warning to the user and prompt for the omitted data). Section names can be easily identified as they end with an ellipsis (...). The sections used by HOTPOT Version 3.0 are:

Globals...

This section is used to store any data about the data in the grid, for example the values of variables used to calculate the grid. The format of lines in this section is: *KeyWord* [= *value*] where the *KeyWord* identifies an item of data (e.g. a variable name) and the optional *value* indicates its setting. (This is the same format as that used in the Grid... section.)

HOTPOT Version 3.0 for Windows does not store any data in the Globals... section. The section title is, however, written into the file as a place holder for future use. When HOTPOT Version 3.0 for Windows reads a grid file it ignores the contents of the Globals... section.

Titles...

This section is used to store text strings which describe the grid and which are to be used as titles or captions on displays of the grid data. Each line is a separate title. Only one title, `Example Grid`, is shown in the example data file, above.

HOTPOT Version 3.0 for Windows only stores one title in the Titles... section. This is the caption of the Grid Display Window or Gridding Window from which the grid was saved. When HOTPOT Version 3.0 for Windows reads a grid file it only uses the first line of the Titles... section, ignoring any subsequent lines.

Grid...

This section is always present and is used to store the dimensions of the grid and then the data values at the grid nodes. All applications using this file format use this section in the same way.

The grid dimensions are stored one per line. The format of these lines is: *KeyWord* = *value* where the *KeyWord* identifies a dimension and the *value* indicates its setting. The keywords are:

`cols` the number of columns in the grid

`rows` the number of rows in the grid

The number of nodes = cols × rows

`Xmin` the minimum x co-ordinate value (i.e. western limit) of the grid

`Xmax` the maximum x co-ordinate value (i.e. eastern limit) of the grid

The distance between columns is given by: $\frac{X_{max} - X_{min}}{cols - 1}$

`Ymin` the minimum y co-ordinate value (i.e. southern limit) of the grid

`Ymax` the maximum y co-ordinate value (i.e. northern limit) of the grid

The distance between rows is given by: $\frac{Y_{max} - Y_{min}}{rows - 1}$

`Zmin` the minimum data node value in the grid

`Zmax` the maximum data node value in the grid

`Znull` the value used to indicate unassigned data nodes (null nodes) in the grid; HotPot conventionally uses the value -9999 for this purpose but other values can be specified

The grid data node values follow. These are stored in row-major order, as displayed on the grid-map, with one value per line. The first value is at Xmin, Ymin (the south-west corner) and the last value is at Xmax, Ymax (the north-east corner). Figure II.1 shows how the nodes in the example grid file are arranged.

The last grid data node value is followed by a line containing the keyword `End`. This marks the end of the file. Its absence indicates an incomplete file.

Appendix III

Gridding and the search radius

The gridding algorithm used in the HotPot program is a simple nearest-neighbour type method. It is, however, quite fast, has minimal memory requirements and is suited to dealing with digitised contour data. This algorithm handles faults as steep slopes.

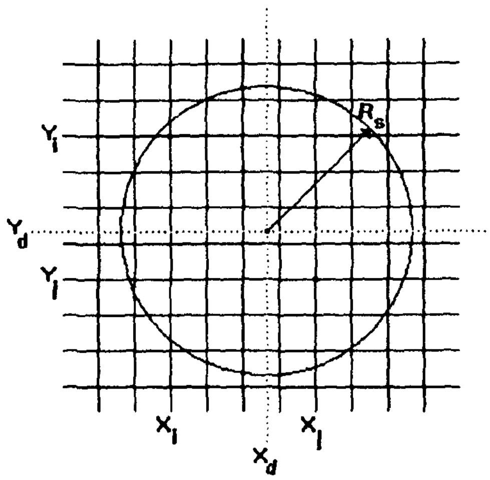

Figure III.1

The search radius, R_s in Figure III.1, defines a circular area around a data point (X_d, Y_d). The value at any grid node located within this area is then adjusted to take into account the value of the data point. The adjustment is distance-weighted, i.e. a grid node, such as (X_j, Y_j), near to a data point will be affected more than will one further away, such as (X_i, Y_i). The search radius is measured in the same units as grid spacing. A good first estimate is the minimum of the grid spacing or the average separation of data points.

The search radius is set by clicking the **Grid...** button in the Gridding Window (section 5.7). This opens a dialogue which shows the existing search radius value in an edit box. The user should edit the existing value or enter a new value then click the dialogue Ok button to initiate gridding.

When the grid has been calculated, the program will display a grid check map of it in the Gridding Window. On the map, each grid node which has had a value assigned to it is shown as a coloured cell. A scale on the right side of the map shows what the colours represent in terms of the data units (e.g. thickness in metres, for isopachs). Grid nodes which are outside the search radii of all data points have no value assigned to them and are called null-nodes. Null nodes are not shown on the map.

The description of the Gridding Window in Section 5.7 of this Manual gives more information on the gridding window and its manipulation.

The grid map is used to assess the reliability of gridding and appropriateness of search radius. It should be checked against the original isopach contour map. If the search radius was too small, then there will be null-nodes, appearing on the grid check as 'holes' (Fig. III.2), within areas of continuous data coverage on the original map. In this case, the gridding operation needs to be repeated with a larger search radius.

If the search radius was too large, then features, especially small structures, seen on the original map will have been smoothed and will not be seen, be indistinct or begin to merge together on the grid display (Fig. III.3). In this case, the gridding operation needs to be repeated using a smaller search radius.

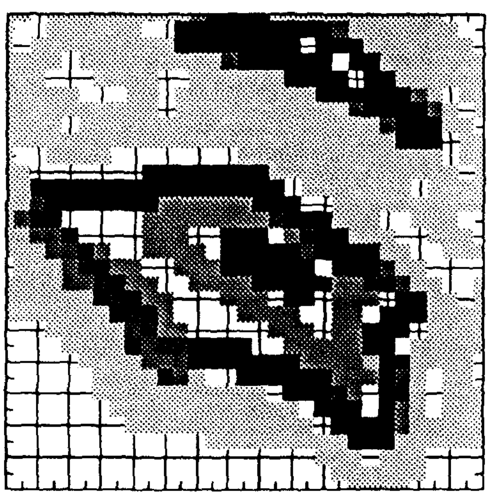

Figure III.2

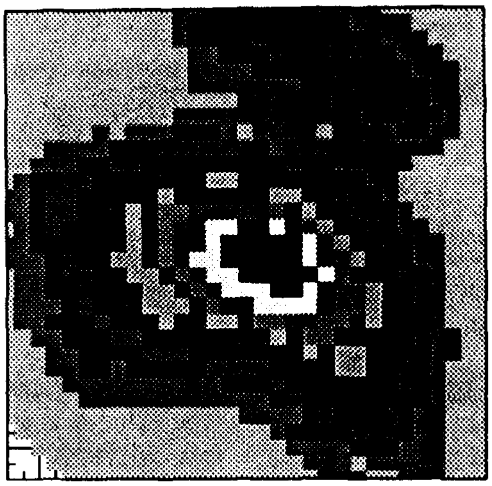

Figure III.3

The best value for the search radius is the one which is *just* large enough not to give any null nodes in areas of continuous data coverage, Figure III.4. It is often found that large search radii give apparently satisfactory results (compare figures III.3 and III.4, both seem acceptable) and care is needed. A good strategy is to first select a too-small search radius, then progressively increase it until no null nodes are seen, then gradually reduce it until null nodes reappear and, finally, to increase it by one step again.

After the grid check map has been examined, the user should respond by clicking the **Accept** button on the gridding window if the gridding is acceptable. If it has been decided to repeat the gridding operation with a different search radius, then the user should respond by clicking the **Grid...** button, in this case the program will open the search radius dialogue ready to repeat the gridding operation.

If no value of the search radius can be found which gives a satisfactory result across the whole map area, it may be necessary to insert some additional *control contours* (these are interpolated between existing contour levels) onto the original isopach map and then redigitise the map. The Tutorial data set shows an example of this process, see the description of gridding the Ruddington Formation in Model 2 (section 4.3.5). Control contours are typically necessary in places such as basin margins where areas of strata having uniform thickness (isopachs widely spaced) are next to areas of rapidly changing stratal thickness (isopachs closely spaced).

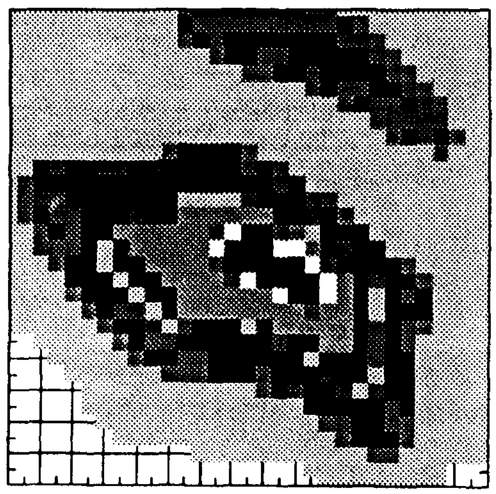

Figure III.4

Where there are only a few isolated null nodes in an otherwise acceptable grid, the Edit Grid Node dialogue (section 5.7) may be used to set their values, based on the values of surrounding non-null grid nodes.

Experience has shown that the visual inspection and comparison method, as outlined above, is more reliable than statistical assessment of goodness of gridding.

APPENDIX IV

Notes on estimation of palaeoheatflow in extensional basins

IV.1 Basin subsidence and extension factors

Evidence for crustal extension during basin development lies in the large normal faults which control basin evolution (Fig. IV.1). However, the evolution of typical extensional sedimentary basins is rather more complex than would be expected from a simple crustal extension mechanism. These basins characteristically show two distinct types of subsidence behaviour. An initial extensional phase of rapid subsidence accompanied by active normal faulting is followed by a secondary phase of more gradual, regional unfaulted subsidence. The first phase is commonly referred to as *syn-rift* or *syn-extensional* subsidence. The second phase is known as *post-rift, post-extensional, sag* or *thermal* subsidence. The two phases may be repeated several times during the evolution of the basin. Examples of syn-rift and post-rift subsidence are given in Figure IV.2.

An important property of the post-rift phase of subsidence is the fact that the rate of subsidence decreases exponentially with time in a manner similar to the progressive subsidence of oceanic lithosphere as it moves away from a spreading ridge, cooling as it ages. Using this analogy, Sleep (1971) proposed that sedimentary basins could be formed by a major thermal perturbation of the lithosphere which produced uplift, erosion and upon cooling, subsidence. However in general, no evidence exists for the required amounts of pre-subsidence erosion, and another explanation for the formation of the majority of basins is required.

Salveson (1978) proposed a qualitative model of lithospheric thinning, which led to basin subsidence, and ultimately to continental separation and the formation of passive continental margins. McKenzie (1978) developed a quantitative model based upon the same concept of lithospheric extension which can explain the observed types of basin subsidence.

McKenzie's model assumes an isostatically balanced crust as part of a lithospheric plate having a linear geothermal gradient and overlying an isothermal asthenosphere. Instantaneous thinning of the lithosphere occurs as a result of horizontal extension that causes its surface area to increase by a factor β. Both crust and lithosphere are thinned by a factor $1/\beta$, this thinning causing elevation of the lithospheric isotherms (Fig. IV.3). The crustal thinning causes an isostatically driven, fault controlled subsidence S_I (the syn-extensional subsidence). Owing to the buoyancy effect of the elevated isotherms, S_I is less than the subsidence that would result from thinning only the crust S_{TOTAL}. With time the elevated lithospheric isotherms relax back to their pre-extension position, allowing the crustal subsidence gradually to approach S_{TOTAL}. This secondary (post-extensional) subsidence S_{TR} has the above mentioned characteristic of an exponentially decreasing rate with time. Also it is of a regional nature, characterised by an absence of normal faulting and may be accompanied by lithospheric flexure. Sediments deposited during the phase of thermal relaxation subsidence commonly overlap the margins of the earlier faulted basin, producing a characteristic 'steer's-head' profile (Dewey 1982), illustrated in Figure IV.4.

Thus:

The total subsidence S(t) at time t Ma after extension can be expressed:

$$S(t) = S_I + S_{TR}(t)$$

The total subsidence S_{TOTAL} attained after complete relaxation of the lithospheric isotherms being:

$$S_{TOTAL} = S_I + S_{TR}(\infty)$$

The initial, syn-extensional subsidence S_I and the time-dependent post-extensional subsidence S_{TR} can be predicted from the extension factor β, using the criterion of local isostatic balance (equations in McKenzie 1978), to produce standard subsidence history curves for various β factors (Fig IV.5).

N.B. S_I, S_{TR} and S_{TOTAL} are conventionally expressed as sediment-starved subsidence values. Thus, the sediment-starved output from HOTPOT can be used to estimate extension factors, either for the basin as a whole (using the grid map mean value) or for parts of the basin using the grid-node extractions.

IV.2 Palaeoheatflow

It is possible to predict the palaeoheatflow from the basin extension factor (equation in McKenzie 1978). Fig IV.6 illustrates a plot of heatflow against time at the *base of the lithosphere* for various extension factors. Basically the curves show a pre-extension sub-lithospheric heatflow of Q_m rising to $\beta.Q_m$ after extension and gradually decreasing with time thereafter. Q_m was assumed by McKenzie to equal about 33 mW m^{-2}. The curves will only predict heatflow at the base of a sedimentary basin in the absence of lithospheric heat sources. In reality, crustal heat sources, particularly in granitic terrains, are very important. Consequently, the absolute values on the heatflow axis of Fig. IV.6 need re-calibration. This can be accomplished if the present-day heatflow, the extension factor and the age of the basin are known, simply by adding a constant value to the heatflow axis such that the predicted present-day heatflow matches the observed heatflow.

Thus, it is possible to predict palaeoheatflows in an extensional basin by assuming the McKenzie Model of uniform lithospheric extension. The balance of evidence from heatflow studies (Buck *et al.* 1988) and deep seismic reflection profiling (e.g. Klemperer & White 1989) suggests that this model is widely applicable. If local evidence unequivocally indicates non-uniform lithospheric extension, then other palaeoheatflow models must be employed. The choice of model, and estimation of palaeoheatflow is, ultimately, the responsibility of the user.

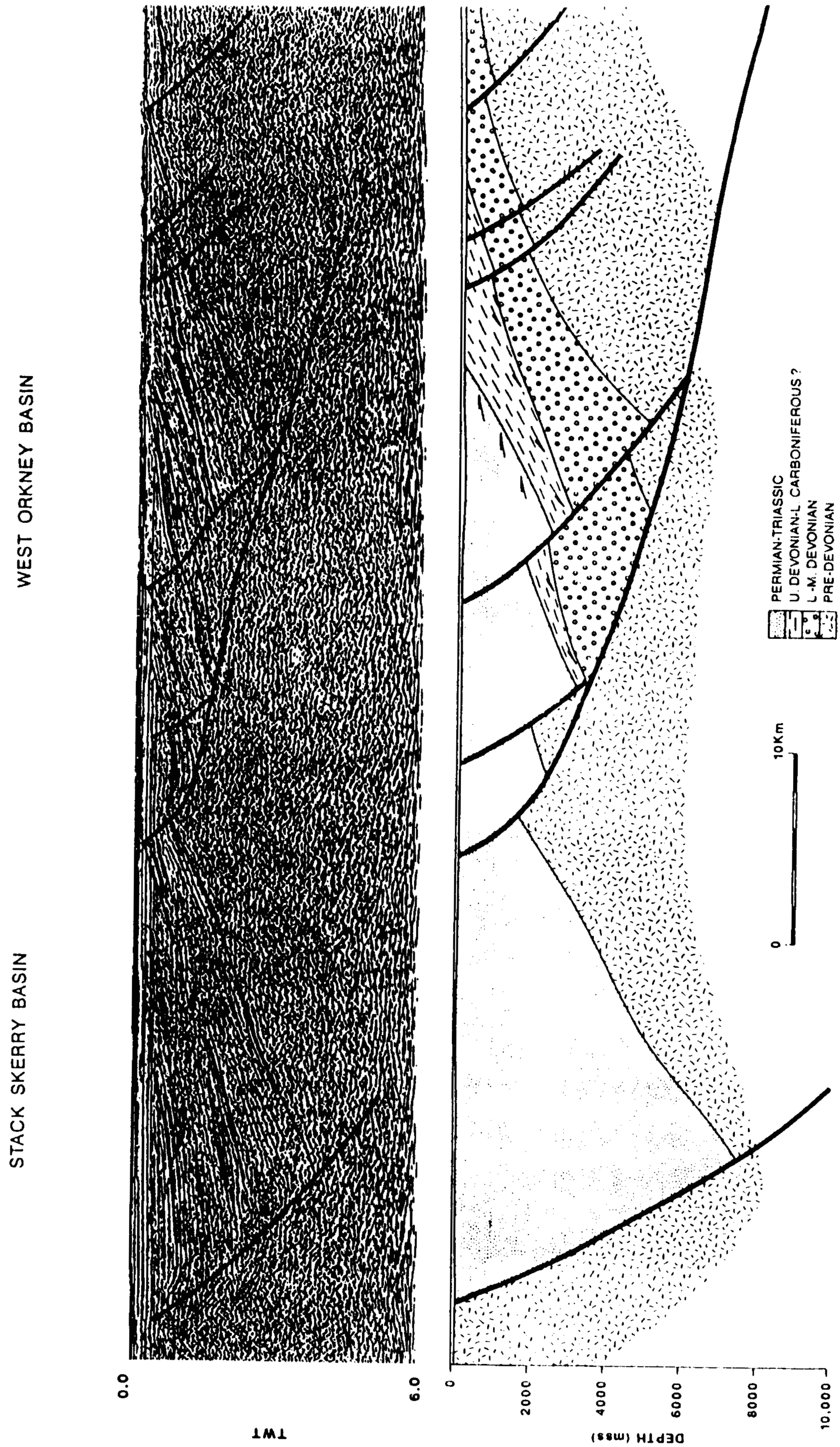

Figure IV.1 Extensional basin with large normal faults, NW European continental shelf (after Earle *et al.* 1989)

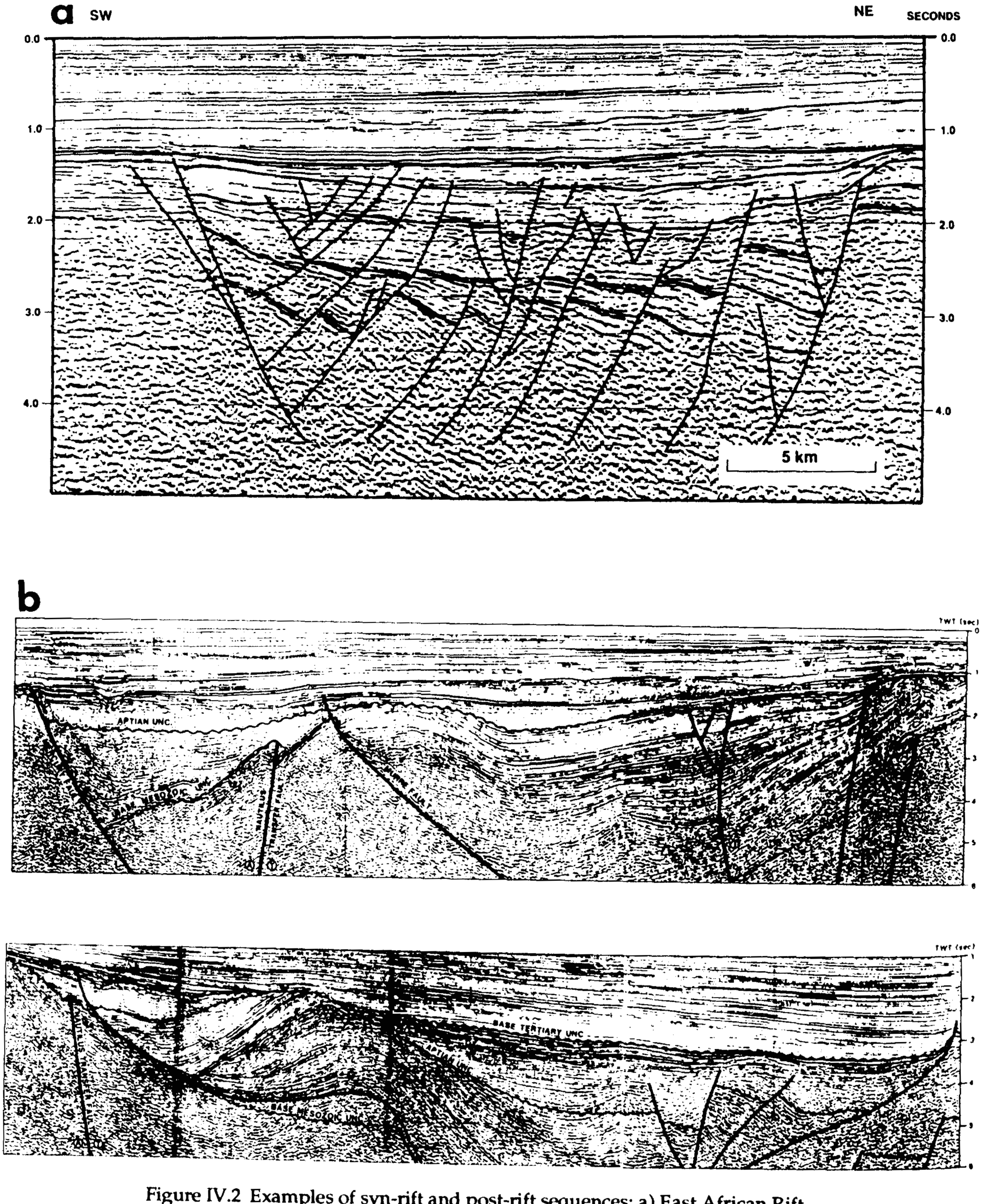

Figure IV.2 Examples of syn-rift and post-rift sequences: a) East African Rift System (after McClay 1989); b) East Canadian Shelf (after Welsink *et al.* 1989)

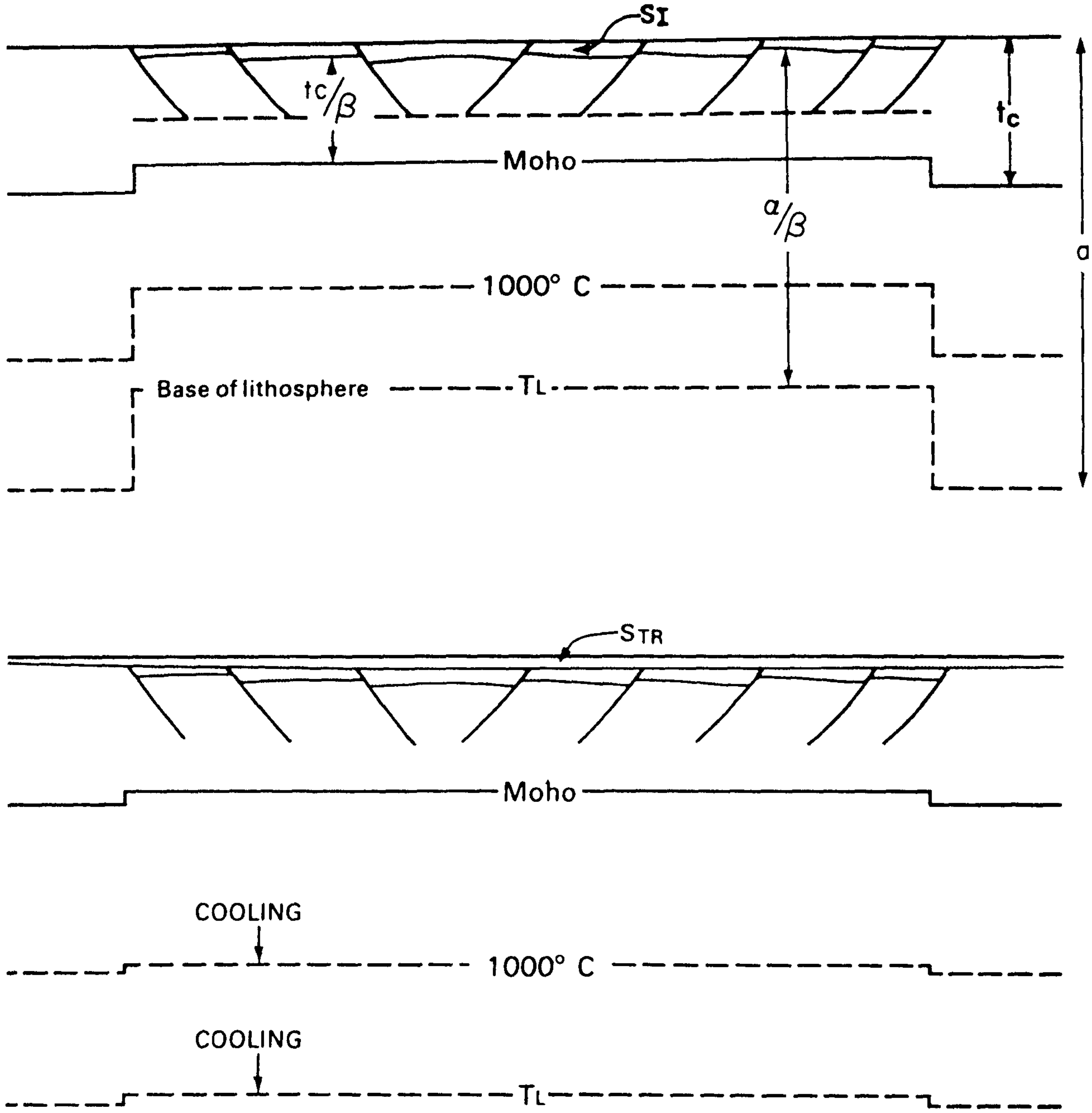

Figure IV.3 Uniform extensional thinning of the lithosphere giving syn-rift subsidence S_I. Thermal re-equilibration (cooling) gives a further post-rift subsidence S_{TR}

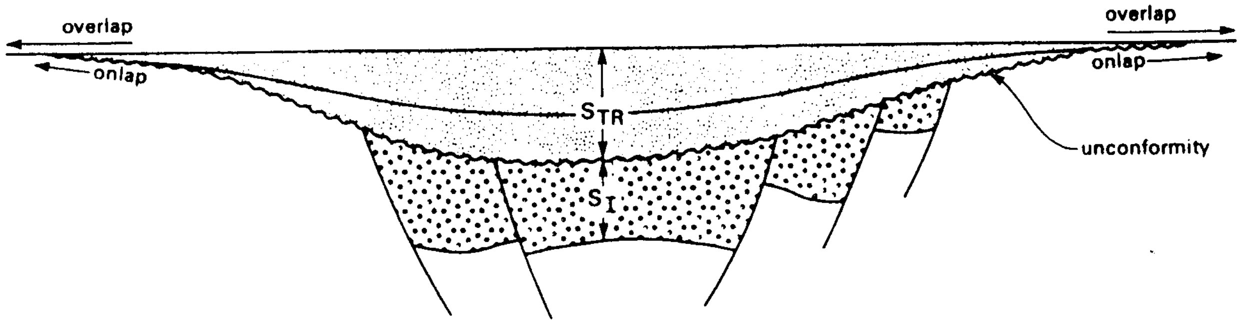

Figure IV.4 Syn-rift and post-rift subsidence phases, giving a 'steer's head' basin profile

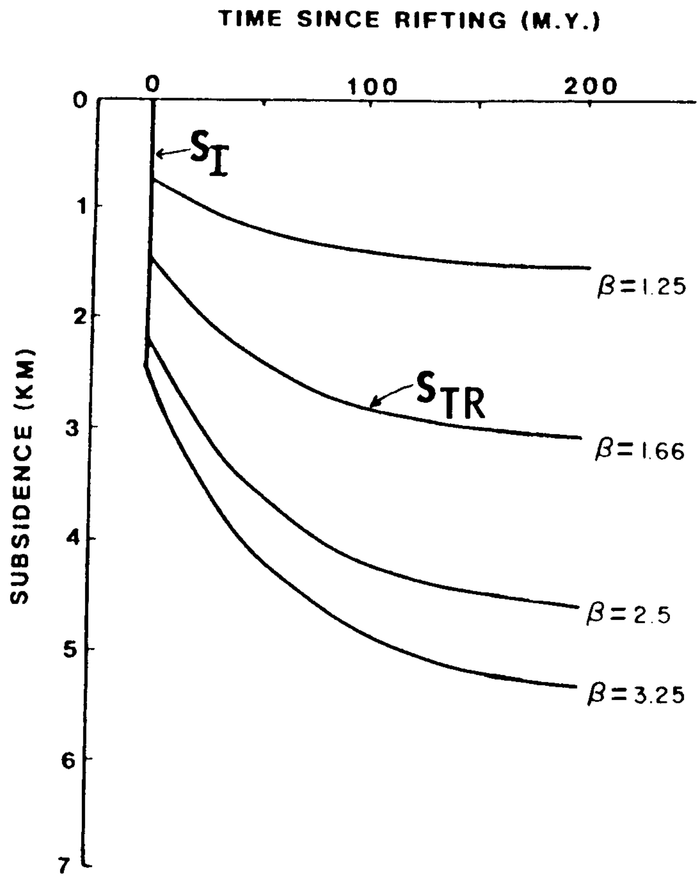

Figure IV.5 Predicted sediment-starved subsidence curves for various values of β

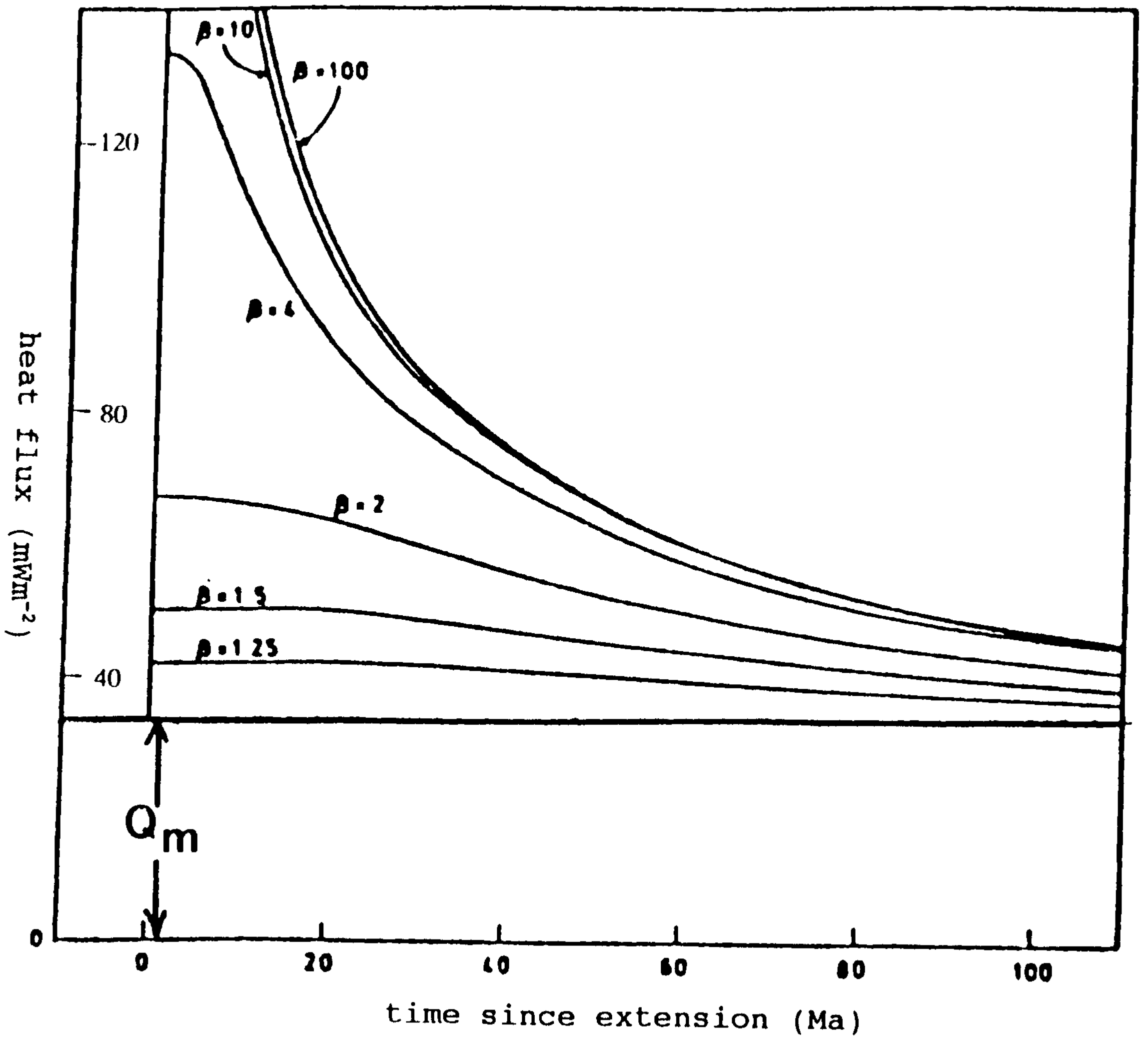

Figure IV.6 Heat flux at the base of the lithosphere as a function of time for various values of β